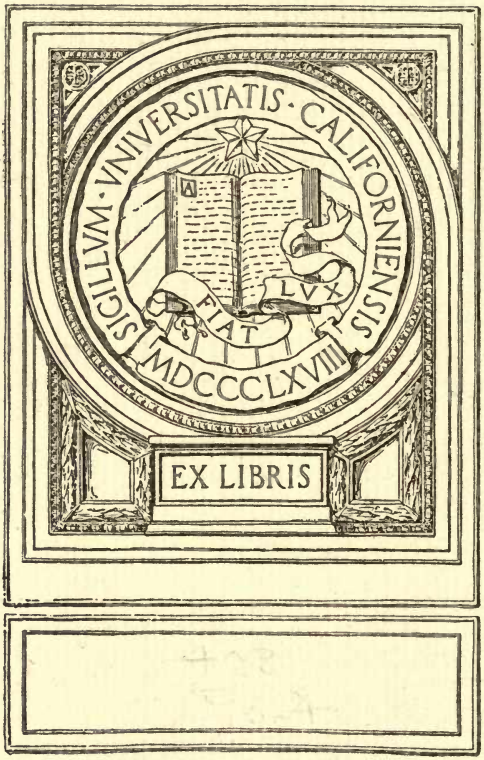
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WATERPROOFING ENGINEERING

FOR

Engineers, Architects, Builders, Roofers and Waterproofers

BY

JOSEPH ROSS, B.S., C.E.

WATERPROOFING ENGINEER

FIRST EDITION

UNIV. OF CALIFORNIA

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PREFACE

WATERPROOFING engineering is not taught in any college, and the writers of engineering papers descriptive of engineering works only rarely embody information on waterproofing. In general, this branch of engineering is given far too little consideration and study in the laboratory and in construction. Its importance warrants a better acquaintance with its laws than exists among those most vitally interested. To remedy this condition and seemingly to supply a real need to the profession, I commenced, early in 1914, a systematic search and diligent study of existing literature on the subject of waterproofing. The field was large but the harvest surprisingly small. Secrecy is the keynote in nearly all commercial literature on waterproofing; but with the aid of chemistry much of this was dispelled. The technical literature is often but semi-illuminating, though some excellent papers and reports have been read before various engineering societies. In fact, the impression gained from perusing the literature extant on waterproofing was, that the subject seemed to be regarded as a sort of necessary evil in engineering, to be overcome as best as the exigency of the case would permit, and if this failed to try again and again until successful. The cost of waterproofing was often the last consideration, but it invariably became the least in the mad effort to successfully waterproof the more important structures. This attitude is fundamentally and morally wrong and economically unsound, because we may find it expedient to justify our ignorance, but never profitable.

In writing this book it is believed that my extensive practical experience and experimental research work in waterproofing engineering has qualified me to undertake this task, the magnitude of which has not been underestimated. Much thought and labor were devoted to the task of compiling and simplifying the text so as to make it understandable by all interested in the subject of waterproofing, which interest, fortunately, is gradually increasing among engineers, architects and contractors.

An effort is also made to explain past and present methods and

materials of waterproofing; investigate their efficiency; draw helpful, if not perfectly exact conclusions, and, where possible, establish standard methods and materials for general waterproofing; and lastly, to emphasize the value of careful study of the whole subject by engineers, especially those engaged in design.

In the hope that it will engender new thought and investigation, and in the belief that waterproofing engineering is now coming into its own, this book is dedicated to the engineering profession.

It has been found impracticable in many cases to acknowledge due indebtedness, for material used, to those writing in technical and engineering society journals on waterproofing; I herewith extend to all my grateful thanks.

Most kind acknowledgment for valuable assistance and suggestions are due and gratefully given to Mr. Percy S. Palmer, C.E., Mr. William F. Holzschuch, C.E., Mr. Samuel G. Margles, C.E., Mr. Max Miller, C.E., and particularly to Mr. Raymond J. Reddy, who, besides contributing information gained from practical experience, has been of great assistance in the preparation of the manuscript and drawings. I also take pleasure in acknowledging my indebtedness to and esteem for Mr. George L. Lucas, General Inspector of Materials of the Public Service Commission, 1st Dist. of New York, in whose department the opportunity and material for writing this book were secured.

JOSEPH ROSS.

NEW YORK,
November, 1918.

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University of California

WATERPROOFING ENGINEERING

CHAPTER I

NEED AND FUNCTION OF WATERPROOFING

Introduction

The art of waterproofing, while having passed its infancy, is not yet in its adult stage of development. That it has developed from a crude understanding and practice is evident from the fact that the ancient Romans would waterproof their structures by building foundation walls so thick that water could not possibly percolate through them.

Searching through both ancient and modern annals for a history of the subject, we are consistently confronted by the scarcity of reliable literature on waterproofing; but it is quite well ascertained that the early Egyptians used asphalt * to waterproof the foundations of the pyramids, that they waterproofed the ground floors of some houses by internal and external applications of bituminous material, and used it also in the construction of cisterns, silos, and other works where waterproofing was necessary: that the Romans were among the first to apply successfully the early principles of waterproofing and were the first successful manufacturers of hydraulic cement. This cement was a natural cement similar to our present day puzzolan cement. Of course, waterproofing engineering as practiced by both the Egyptians and Romans must be taken in a restricted sense, for the art, as now developed and as we comprehend it to-day, was quite unknown then.

Conditions Creating Necessity of Waterproofing. It has been quite definitely proven that water is practically a universal solvent; i.e., given time and water, especially sub-surface water, very few things will resist the deteriorating effect of the latter. At

* For earliest history of asphalt, see: "Manufacture of Varnishes and Kindred Industries" by Livache and McIntosh, Vol. 2, p. 30.

certain distances below ground surface, varying both seasonally and locally, water is nearly (within several feet) at the same level (called ground-water level) throughout the year. All engineering structures, of course, have their foundations in earth or rock (which is the same thing so far as water pressure is concerned) and may be partly or entirely submerged by ground water; consequently they are subject to considerable water pressure and to the disintegrating influences of the acids or alkalies usually present in ground water. It is also evident that due to uneven settlement and continual variations of temperature, cracks may develop in superstructural and subsurface masonry, foundation walls, etc., through which water will seep regardless of how minute these cracks may be; hence waterproofing in some form becomes essential to the life and stability of the structure. What this form of waterproofing should be is a problem not susceptible to precise mathematical solution, but by a careful study of conditions and with the help of past and present experience, and a knowledge of the chemical and physical properties of waterproofing materials, a form or method can be devised suitable for any special condition. Therefore, a knowledge of all manner of waterproofing systems and the properties of suitable materials becomes indispensable, at least to the engineer and architect, who usually specify how and what should be used under given conditions or for particular structures.

Waterproofing—The Universal Structural Bodyguard. Our era has rightly been designated the "Concrete Age." In fact, the growth of our civilization might be measured by the quantity production of cement, and the commercial progress of a community might be measured by the number and size of the concrete structures within its boundaries. In the not distant past, most solid structures were composed of ordinary brick or stone masonry, and to-day not a few are similarly constructed, but these are rapidly being superseded by concrete and steel. Even for dwellings concrete is becoming more adaptable and is being used more every day, and the prediction is made that the future will see a predominance of concrete buildings of all varieties.

But co-ordinately with the use of concrete, or nearly so, is the provision of a "body guard" in the form of waterproofing. For, as iron and steel must be protected from corrosion, so must concrete be protected from disintegration, but unlike the former, concrete must also be made impermeable. Water, by its capacity of alternate freezing and thawing, reacting upon concrete as ordinarily made, with its inherent porosity, wherein water may lodge and exert its

expansive or disintegrating forces, is the bane of such structures. On the other hand, water pressure is an added bane of subsurface structures. All of these causes and their effects preclude the possibility of making a permanently element-resisting structure without some form of protection. Waterproofing affords this protection. Efficient waterproofing is therefore rightly co-ordinate with concrete, the universal structural material, and the materials used to accomplish this should therefore be classed as structural materials. Waterproofing not only protects but prolongs the life of any structure to which it has been properly applied. Proper waterproofing materials intelligently and adequately applied is the keynote of success in making all engineering structures watertight. But even appropriate materials unsystematically applied, or vice versa, will not produce a waterproof medium. This emphasizes the necessity of knowing all the related factors in waterproofing a structure as well as in designing it.

Density for Watertight Concrete. In the making of concrete it is attempted to duplicate natural stone, in form, design and color, but especially in density. The density of average concrete is more nearly equal to that of the lighter stones (see Table I), though in practice the effort is universal to make it approach that of the heavier ones, which effort has the desirable effect of reducing its porosity. To accomplish this, engineers often and rightly resort to scientific proportioning of the aggregates, increased time of mixing, careful tamping, spading and closer supervision of construction, or again, by incorporating certain water-repellent or void-filling ingredients in mass concrete or in the mortar used for laying up the stone masonry. Where these precautions are impossible or inadequate, the structure may be placed in or surrounded with an impervious bituminous sheet-layer or membrane, forming an external waterproofing medium.

From Table I it is evident that not only concrete but all kinds of stone are more or less porous. Hence this property, being inherent in all stones, must not be overlooked in construction work where it may cause damage. But this is especially true of concrete, because, as is obvious from the table, it is very difficult to make ordinary concrete denser than average limestone, and consequently, its porosity being always present, is more menacing to the integrity of any concrete structure.

Ordinary concrete will absorb water more readily than is generally supposed. The presence of alkaline, such as magnesium or sodium sulphate, or of acid in ground water, tends to attack the cement in

some manner not yet definitely known, and is one of the chief causes for the disintegration of concrete. This is especially true of the action of sea water on concrete. Other causes tending to disintegrate, or in some manner to disrupt concrete, are electrolysis, temperature changes and uneven settlement. A brief review will be made of each of these causes and their effects.

TABLE I.—AVERAGE WEIGHTS, SPECIFIC GRAVITIES, AND ABSORPTION OF VARIOUS STONES AND CONCRETES

STONE

Kind of Stone.	Weight, Lb. per Cu. Ft.	Specific Gravity.	Water Absorbed,* Lb. per Cu. Ft.	
			Max.	Min.
Trap	180	2.92	1.03	0.23
Marble	170	2.72	1.04	0.10
Slate	168	2.70	2.10	0.05
Granite	168	2.70	2.77	0.04
Limestone	162	2.60	6.62	0.02
Conglomerate	162	2.60	3.71	0.60
Sandstone	150	2.40	11.60	0.02
Brick	125	1.85	18.75	....
Gravel	100	2.65	....	....
Cinders	95	1.50	....	....

CONCRETE

Kind of Aggregate.	Weight, Lb. per Cu. Ft.	Specific Gravity.	Water Absorbed, Lb per Cu. Ft.* †
Trap	155	2.48	3.13
Conglomerate	150	2.40	....
Gravel	150	2.40	3.66
Limestone	148	2.34	3.47
Marble	144	2.30	2.48
Sandstone	143	2.29	....
Cinders	112	1.79	9.61

* For exact method of determining absorption of water per cubic foot of rock, see American Society of Civil Engineers Transactions, Vol. 82, p. 1437 (1918).

† The figures in the last column were estimated from tests made on 6-inch cubes of 1 : 2 : 4 concrete.

Source and Location of Ground Water and Its Effect on Concrete

Since water is the all-important cause creating the necessity for waterproofing, we will consider briefly its source and general location in the ground.

Ground water is that part of rain, hail or snow that has percolated through and accumulated in the ground as water, either in soil or in rock, usually in consequence of an underlying impervious stratum which materially retards or totally prevents its further percolation downward. The upper surface of ground water is called the water table, or the ground-water level. The depth of ground-water level below the earth's surface varies with the locality, topography and character of the earth's material.* Ground-water level has nothing to do with mean high water, though in some localities they are at the same elevation; the latter surface, however, is usually lower. Proper drainage will, of course, lower ground-water level, and this is often resorted to in order to obviate the need of more extensive waterproofing. But as the limit of this level is mean high-water level, its successful possibilities are not unlimited. So far as waterproofing is concerned, therefore, the two water levels require equal consideration, because one or the other, or both, are always operative. A clause in the specifications for waterproofing the new subways in New York reads: " waterproofing of the structure will be limited to the roof and to those surfaces near ground water, or mean high water, if ground-water level is found for any reason to be below mean high water." Flood water is less difficult to control than either sea or ground water, and only affects certain localities at certain times, often due to accident. Its effects are readily overcome by proper drainage, damming or simple waterproofing methods.

Waterproofing and Drainage as a Protection against Ground Water. The most general effect of ground water on engineering works is to necessitate these works being constructed with special waterproofing considerations. The earth below ground-water level remains wet constantly, often subjecting an underground structure to a large hydrostatic head. It is this head of water which requires careful attention and design to make it effective. And what cannot be accomplished by design alone can be accomplished by including a system of waterproofing to prevent the percolation of water through the more or less porous concrete, or through slight cracks that may develop in it.

* Turneaure and Russell, " Public Water Supply."

An underground system of drainage is often included even where a complete system of waterproofing is called for and provided, as in the above cited subway specification, to wit: "Every part of the railroad must, so far as possible, be so arranged that any water finding access thereto will be led away automatically to the city sewers. Where the railroad is on an inclined gradient, and is constructed in dry, porous soil, the floor of the railroad may be depended on to act as a conduit. At the bottom of the inclined gradient connection must be made with a sewer or with subdrains lying beneath the railroad and draining into the sewers.

"Along such parts of the work where the soil is not porous, or where the floor of the railroad cannot, in the judgment of the engineer, be used as a conduit there shall be laid, beneath the rail level and on a continuous descending gradient, drain pipes of vitrified tile. Each drain shall be laid in the concrete or directly in the soil with tight or open joints, as directed, and in such manner and in such position as, in the opinion of the engineer, local circumstances require."

Ineffectiveness of Weep Holes in Preventing Cracks in Masonry. Concrete retaining walls and abutments, but more especially the former, are, as a rule, provided with weep holes to take care of the water at their backings. The practice adhered to is to let one weep hole 3 or 4 inches in diameter suffice for every 3 or 4 yards of wall front. But experience has demonstrated that such weep holes do not always suffice to protect a wall against water pressure (in so far as it affects percolation), still less against deteriorating agencies in the water, and least of all do they prevent surface disfiguration due to efflorescence. Neither do weep holes prevent subsequent and uneven settlement with consequent cracking of the masonry. The reason is quite obvious; for weep holes too often and too easily become clogged, and are in consequence unable to carry off the storm water rapidly, which is their main function, consequently the water accumulates in the backfill and backs up behind the wall, causing, with the aid of head and frost, the damages referred to above.

While waterproofing would not overcome all of these defects, it would undoubtedly eliminate to a marked degree their effects. In fact, the tendency in present-day construction is to eliminate weep holes and substitute a type of waterproofing meeting the purpose and need of the structure. Thus it is seen that ground water is the elemental cause against which concrete structures must be protected by the application of some waterproofing material or drainage system, or both.

Causes and Effects of Porosity in Concrete

Cement mortar and concrete, even when made under laboratory conditions, are far from being dense enough to completely prevent the percolation (independent of absorption) of water through them if time is reckoned as a factor. The volume of total voids in mortars averages about 26 per cent, and in concrete, of proportions commonly employed in practice, the voids range from 13 to 17 per cent. That this is a common as well as a serious condition follows from the fact that many laboratory tests show that 70 to 80 per cent of the tempering water evaporates, leaving behind it the cells that it formerly occupied, and as these cells are more or less connected, a system of ducts through the entire structure is established. This cellular condition creates a natural capillary passageway for water to enter and be absorbed in the mass. But the permeability of mortar or concrete is practically independent of that form of porosity wherein the voids form an unconnected system, but the freezing effect is quite different, and is referred to below.

At this point it is probably well to remind the reader not to confound porosity with either permeability or absorption, for concrete may be porous and yet absorb little water, and it may be absorptive, and yet not permeable.

Porosity of concrete may be defined as the net-work of unconnected voids or honeycombing of its mass by the entrained air and water.

Absorption of concrete is the property of drawing in or engrossing water into its pores or voids by capillary action or otherwise.

Permeability (or percolation) of concrete may be defined as that quality, due to cracks or connected voids, which permits the flow of a liquid through it.

Effect of Freezing Water on Concrete. All three states, that is porosity, permeability and absorption, are allied, and each one in some way is detrimental to concrete, for, whether water is entrained in the mass * or flows through it, or is absorbed by the concrete, when it freezes some form of damage is done. There are but few bonds strong enough to resist the expansive force of freezing water. It increases its bulk approximately 10 per cent, and the consequent expansive force is probably more than 10,000 pounds per square inch. A section of concrete 100 feet long, under 100 deg. Fahr. (55.5 deg. Cent.) change in temperature, will contract or expand $\frac{66}{100}$ of an

* See striking example in Engineering News, Vol. 77, No. 9, p. 356.

inch. This change is infinitesimal in comparison to the volumetric change in freezing water; hence the need for eliminating the porosity of concrete and also preventing the percolation of water through it. For evidence of the effect of the expansive force of freezing water, one need but observe the physical condition of natural stones exposed to the elements for a more or less protracted period of time. Even mountains, with their proverbial strength, are crippled by this agency. A very striking example of the effect of this tremendous mechanical force is seen in the crumbling of the exposed portions of the rocky Palisades on the New Jersey shore of the Hudson River.

Effect of Sewage and Sea Water on Concrete.* That the durability of concrete is materially impaired by its porosity is strikingly illustrated by the easy prey it falls to the action of alkali waters, sewage and sea water.

The alkalies contained or formed by or in these waters, which are most active in causing disintegration of concrete, especially when allowed to penetrate into the interior of the mass, are the sulphates of sodium, magnesium, and calcium.

Disintegration of concrete in sewers and sewage disposal works, whether due to the use of poor materials, poor workmanship, or lean mixtures, each of which tends to decrease the density of concrete, has been found to take place above the normal surface of the liquid contained. This action probably results from the fact that quantities of hydrogen sulphide are evolved from the sewage. This sulphide is produced in two ways: (*a*) By the bacterial decomposition of sulphur-containing proteins and related compounds, and (*b*) the reduction of sulphates which are contained in unusual amounts in some water supplies. Of the two, the second seems to be more important. The hydrogen sulphide which escapes as gas from the sewage is partially dissolved in the moisture on the under side of the roof and concrete walls. Here it is oxidized to sulphuric acid partly by atmospheric oxidation and partly by bacterial action. The sulphuric acid acts upon the calcium compounds in the concrete, forming calcium sulphate, thus breaking down the concrete.

Where the effect of sea water on concrete has been other than mechanical, it is probable that disintegration is caused by the substitution of magnesium oxide (MgO) from the sea water in the place of the calcium oxide (CaO) of the cement, as well as to the decrease in the proportion of silica and the increase in sulphuric anhydride (SO_3). Interesting examples of these processes will be found in Engineering and Contracting, Vol. 57, No. 26, p. 580. The United States Bureau of Standards, after some extensive tests on the " action

* American Railway Engineering Association, Vol. 14, p. 834.

of the salts in alkali water and sea water on cements," described in Technologic Paper No. 12 of the Bureau, remarks as follows:

"The cause of the disintegration of cement structures is not certain, though it is almost universally believed that it is the reaction of sulphate of magnesia of the sea water with the lime and the alumina of the cement, resulting in the formation of hydrated magnesia and calcium sulpho-aluminate, which crystallizes with a large number of molecules of water. Other constituents of sea water, especially sodium chloride and magnesium chloride, have also been noticed to attack the silicates of the cement and produce rapid disintegration."

To safeguard concrete structures against the destructive action of the above agents, it is necessary to make dense, impermeable concrete by the use of a well-graded aggregate, moderately rich mixture, proper consistency and good workmanship, and allowing the concrete to harden under favorable conditions before being exposed; or, where practicable, by applying a surface mortar coat from 1 to 2 inches thick. Both of these methods are included in distinct systems of waterproofing, which are explained in Chapter II. In Appendix II will be found more explanatory information on this interesting phenomenon. For experimental confirmation the reader is referred to the above Technologic Paper.

Destructive Effect of Electrolysis on Concrete

In the principle of electrolysis we have a very formidable agent at work against the integrity of concrete structures; one that requires careful study and attention in structural design and during construction. Its effect is mechanical and, though not widespread, is as disastrous as the freezing of water in concrete. The passage of an electric current through reinforced concrete causes, amongst other effects, oxidation of the iron reinforcement. The oxides formed occupy 2.2 times as great a volume as the original iron and the pressure resulting from this increase of volume is very great. That it is possible to damage reinforced concrete structures by stray currents from electric railways, power-houses, and general ground connections is an established fact.* Electric currents passing from the reinforcing material into the concrete—for electrolytic action takes place only where the current leaves the conductor—cause corrosion of the reinforcement and cracking of the surrounding concrete more or less seriously, but always sufficiently to permit the percolation of water through it, which further aids electrolysis; this, in turn,

* Technologic Paper No. 18 of the Bureau of Standards, U. S. A.

creates more cracks, thus permitting more water to enter and attack the reinforcement, whence the action is further enlarged until there arises serious danger that rupture may ensue.*

Elimination of Electrolytic Effects. Partial elimination of electrolysis is possible by the selection of courses of masonry or concrete of a high specific resistance and their careful distribution about the structure. As an illustration: If blocks of granite are interposed between the footings of a building and the soil, the tendency of the building to pick up stray currents is materially reduced because of the high electrical resistance of the granite. It may be impracticable to take these precautions, but it is nearly always possible to surround the footings with a waterproofing membrane which will accomplish the desired end. See Fig. 1.

Various proportioned concrete aggregates offer greater or less resistance to electrolysis with a showing in favor of what would ordinarily be called a poor concrete.

Table II † shows the specific resistance of concrete made of Old Dominion cement, river sand and crushed trap. The specific resistance of concrete will, of course, vary greatly with the aggregate, method of making, etc., and the values given below are indicative only of the order of magnitude of the specific resistance that may be expected.

TABLE II.—ELECTRICAL RESISTANCE OF MORTAR AND CONCRETE

Proportion of Mortar.	Resistance in Ohms cm.³	Proportion of Concrete.	Resistance in Ohms cm.³
Neat cement	3500	1 : 2½ : 4	8000
1 : 2	2300	1 : 3 : 5	8200
1 : 4	2100	1 : 4 : 7	9900

In general, complete protection from electrolytic effects is not practically possible by any other means than efficient waterproofing. What form of waterproofing should be used for this purpose depends on local conditions and the type of structure, but invariably that system which is of a membraneous nature will be most efficient. Precautionary measures against electrolysis must be taken both in the city and in the country, but perhaps more so in the country because electrical feeders are usually much better protected in cities, where laws are enacted for this purpose.

* Engineering News, Vol. 66, June 8, August 3 and 17, 1911; Vol. 68, July 12, December 19, 1912.

† Technologic Paper No. 18 of the Bureau of Standards, U. S. A.

Effect of Temperature Changes on Concrete

A fourth disrupting force, and one not easily overcome, is change of atmospheric temperature, to which influence can be ascribed many concrete failures. Additional steel embedded near

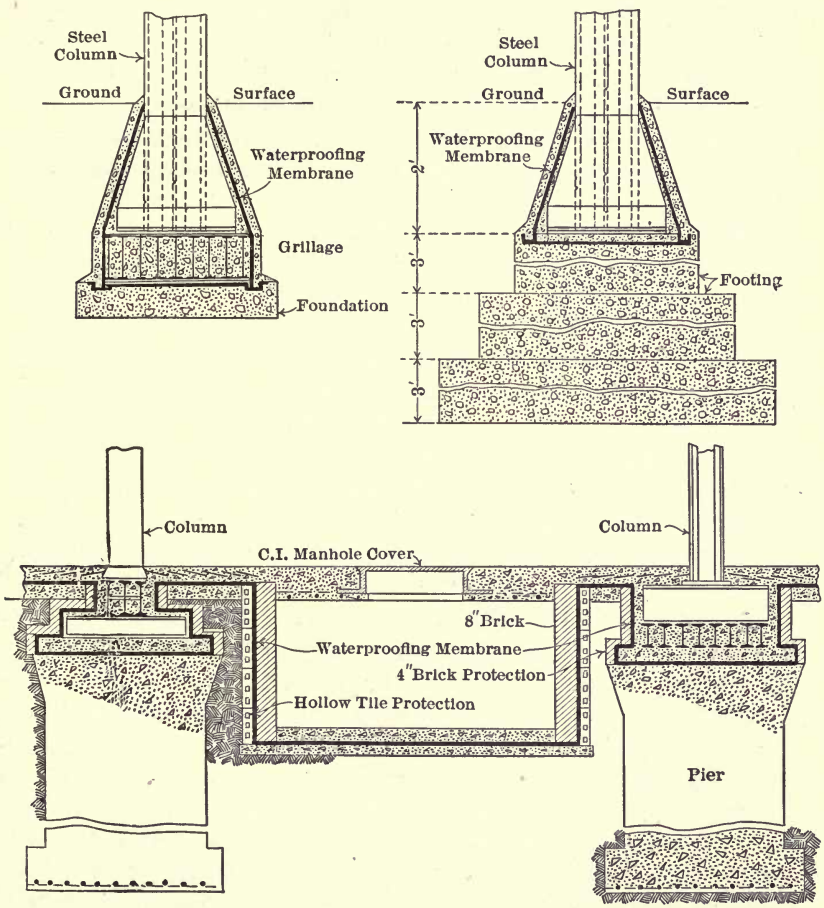


Fig. 1.—Methods of Waterproofing around Column Bases and Footings to Prevent Electrolysis.

the surface of the concrete is one of the means employed to combat this force. The effect of the temperature change, however, is never wholly lost, especially, though rarely, where concrete is depended upon to take tensile stress. Just to illustrate: Assuming

the coefficient of expansion of concrete as .0000055 per deg. Fahr., and its modulus of elasticity as 2,000,000 pounds per square inch, then the stress due to temperature is 11 pounds per square inch per degree change of temperature, or, for 60 deg. Fahr. it is 660 pounds per square inch, which is double the ultimate unit tensile stress for concrete. A temperature difference between summer and winter of twice 60 deg. Fahr. is not uncommon in certain parts of the United States.* Fortunately, in this country, tensile strength of concrete is neglected. It must not be supposed, however, that steel reinforcement, however efficiently placed, does more than diminish the size and distribute the cracks which are caused by temperature changes. But this result is sufficient to materially increase the impermeability of the structure.

Effect of Expansion Joints in Masonry. In steel, a change of temperature of 1 deg. Fahr. causes a stress of about 200 pounds per square inch if resisted. In concrete a change of 18 deg. Fahr. causes an equal stress if likewise resisted; that is, if expansion joints are not provided to take care of the expansion and contraction, the resulting stresses may cause cracks in the structure, with the usual result of disfigurement due to efflorescence and damage due to seepage. But, on the other hand, these very expansion joints create one of the most urgent needs for waterproofing a concrete, or for that matter, any form of masonry structure.

Expansion and contraction in a structure and their resulting stresses are due to changes in atmospheric temperature or change in temperature of the concrete while it is setting and hardening. This latter temperature change may be as high as 150 deg. Fahr., depending on the thickness of the masonry.† With steel reinforcement to take care of stresses resulting from temperature change, the cracks are kept small, but not entirely prevented. The expansion joints necessary to relieve the atmospheric temperature-change-stresses require special study. Their form and location in a structure not only have a great bearing on the stresses set up in it but also on their effectiveness. While expansion joints tend to relieve the effects of these stresses, they are not always effective in preventing hair cracks or cracks at angles in the structure, or leakage through the joints themselves as commonly constructed. Hence the need of an efficient type of waterproofing, in conjunction with well-designed expansion joints, which together will most effectively overcome these defects.

* American Civil Engineers' Pocket Book, 2d Edition, p. 1255.

† Taylor and Thompson, "Concrete, Plain and Reinforced," 2d Edition, p. 285.

Effect of Uneven Settlement on Masonry

A fifth important destroying agency to consider in concrete construction is uneven settlement. An inequality of bearing power will cause uneven settlement in a structure. Only the most careful designer can minimize and perhaps eliminate settlement, which sometimes causes unsightly cracks, and, of course, reduces the impermeability of the structure. Retaining walls are particularly subject to stresses of this character. Bridge abutments and building foundations sometimes suffer a good deal from this cause. When to this is added the vibration in each, due to traffic or the operation of machinery, the injuries are enhanced in a manner that invites further damage when water enters the cracks.

Where masonry walls support backfill behind them and tracks above them, settlement may occur due to pounding of trains on the tracks. Or, if drainage behind the walls is, or becomes, inadequate for any unforeseen reason (due to clogging of weep holes, for instance), the earth underneath the foundation may be undermined, causing more or less settlement with consequent cracking and the percolation of water. Concrete reservoirs often develop cracks from this cause, and in spite of their eventual silting-up often continue to be troublesome until properly waterproofed. In fact, it most generally happens that settlement cracks are too large to be closed up by silting, or there may be no silt to depend on, as when building in rocky strata. But even where silt is abundant and is depended upon to close up any cracks, it always takes time, invariably defaces the structure, and the cracks may reopen by further settlement. Consequently, nothing remains to be done but to waterproof the structure, in a manner that will minimize or vitiate the effects of this agent.

Hygienic Need of Waterproofing. The above considerations undoubtedly establish the fact that the ill effects of the inherent porosity of concrete and the perviousness of general masonry should be eliminated as far as possible as a matter of economy and safety. And, incidentally with the exclusion or repulsion of water (which action depends on the system of waterproofing employed) from a concrete structure, that is, with a dampproof and waterproof condition of a structure, follow other results and benefits that have both an æsthetic and hygienic effect which can ill afford to be overlooked. Concrete construction which proceeds with the idea of permanency should embody the co-ordinate functions of dampproofness and waterproofness and uniform surfaces, free from

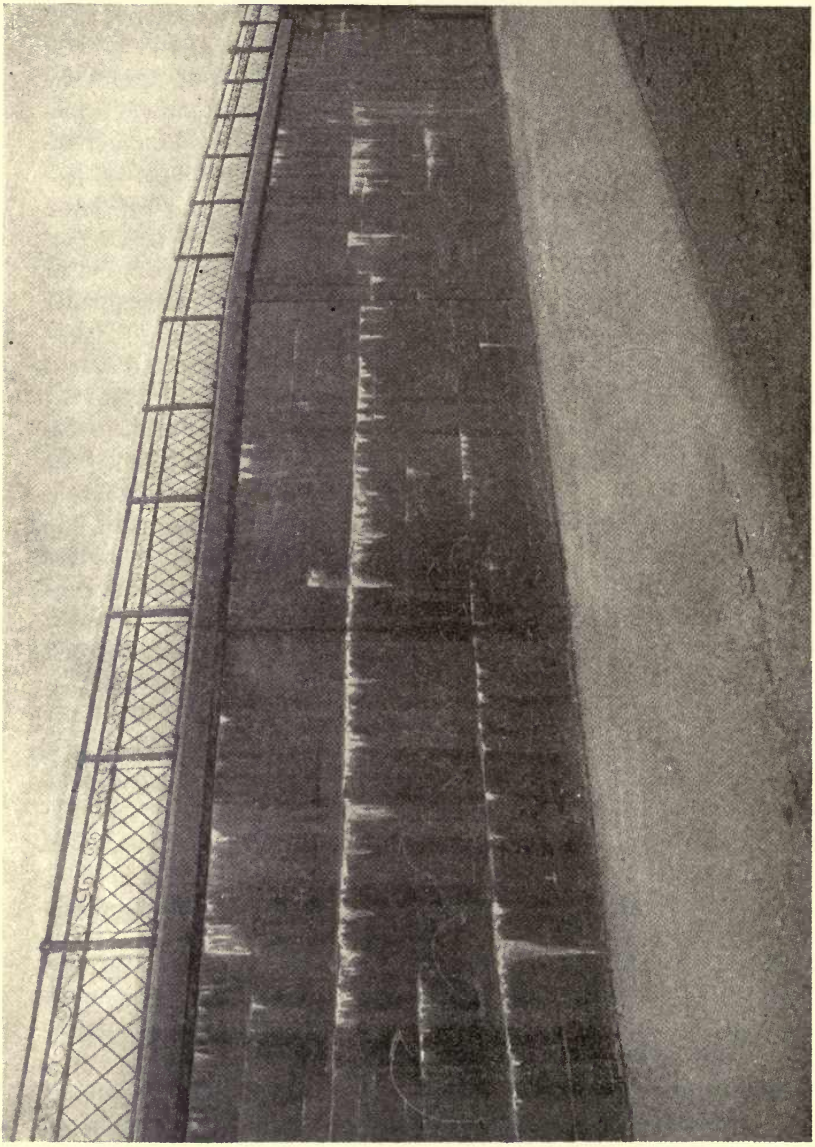


FIG. 2.—Retaining Wall Showing Leakage and Efflorescence at Construction Joints.

unsightly blotches and discoloration by efflorescence. (See Fig. 2.) The latter defect in concrete and brick masonry is mainly due to the absorption of atmospheric moisture, which dissolves the salts of soda, potash, magnesia, etc., present in the cement and, on evaporating, deposits them on the surface. But in many instances rain or ground water from behind walls or other structures percolates through the mortar or expansion joints, day's-work planes, cracks, or through the very body of the masonry, carrying with it also various oxides which leave rusty looking streaks or white and yellow patches on the face of the masonry that often makes an eyesore of an other-

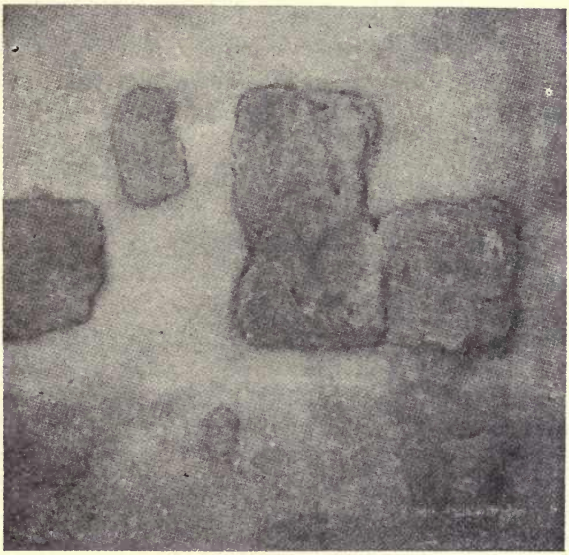


FIG. 3.—Evidence of Exudation of Lime Salts through Wall Unprotected by Waterproofing or Dampproofing.

wise beautiful engineering structure. (See Fig. 3.) This condition is true of masonry both above and below ground, although in the latter case it is usually neglected. Where only this condition is to be prevented, the incorporation of a bona-fide integral compound is the most efficient means of accomplishing the desired end. Where, however, cracks are inevitable, only a membraneous system of waterproofing can overcome this defect.

In building construction, the absorption and retention of moisture in walls above ground, and moisture and water in cellar and foundation walls and floors below ground, cause dampness which is harm-

ful to health. Hence dampproofing, particularly in exposed buildings, assumes grave importance, and further emphasizes the need of waterproofing, because this always acts as an effective dampproofing; that is, any structure that has been waterproofed has necessarily been dampproofed. There are conditions, however, where dampproofing alone is necessary or possible, as for instance, exposed walls of buildings. These are usually and successfully coated with a bituminous compound or covered with a thin ($\frac{1}{4}$ inch to $\frac{1}{2}$ inch) layer of plaster or cement mortar. Sometimes a waterproofed cement mortar coat is applied an inch or less in thickness for this purpose, and if the work is carefully done so that no separating plane is left or peeling follows, proves an efficient dampproofing medium.

From the foregoing it may be concluded that waterproofing requires as careful consideration in engineering work as fireproofing does in building work. With so many deleterious agents constantly at work, not only on concrete but on all masonry, the imperative need of protecting all manner of structures against them, or against their effects, becomes apparent. The form of this protection is known by the broad name of waterproofing, and the art of applying it as waterproofing engineering. To dampproof is to make a structure impervious to moisture. To waterproof is to render a structure impervious to moisture and water. To accomplish this is to preserve and lengthen the life of a structure, and this in turn tends towards economy, which is an equally important consideration to the architect or engineer in design and construction as to the builder or owner of a structure.

CHAPTER II

SYSTEMS OF WATERPROOFING

Progress of the Art of Waterproofing. The progress that the art of waterproofing has made since it began to receive serious consideration is quite notable. It is difficult to affix any definite date to the adoption of scientific waterproofing, but even as late as 1870 waterproofing engineering, in the broad sense we are now considering it, was more speculative than experimental. About this time the "Sylvester Process" of waterproofing (originated in England) came into vogue among American engineers, and while it still is sometimes employed, it has, in the main, been superseded by better methods and materials. Not that asphalt was unused prior to this date for waterproofing purposes, but there seems to have been no certainty of results connected with its use.

Since this period and up to comparatively recent times there were developed four distinct systems of waterproofing, namely, "Membrane," "Mastic," "Surface Coating," and "Integral." In the last decade, a fifth system—one that will often obviate the need of any of the first four—has received wide experimentation with very good and consistent results. This system is applicable only to concrete structures and is designated "Self-densified Concrete." Another recent system of waterproofing is known as the "Grouting Process," which is especially applicable to subsurface structures such as tunnels and cutoff walls either in rock or earth. Both of these systems will be considered in due order.

The modern systems of waterproofing then, if arranged in the order of their development, appear to be as follows:

(1) "Surface coating."
(2) "Membrane." *
(3) "Mastic."
(4) "Integral." †
(5) "Self-densified concrete."
(6) "Grouting process."

* Mr. E. W. DeKnight claims to have introduced this term in 1902; but this term as applied to waterproofing has only been used extensively in the last decade

† This term as applied to waterproofing was used as far back as 1875 but not extensively until the last decade.

Surface Coating System of Waterproofing

Definition, Purpose and Development. The surface coating system of waterproofing refers to the application of: (1) In impervious coating of plastic or liquid bituminous materials; (2) various liquid hydrocarbons, and chemical salt solutions forming, usually, water-insoluble compounds; (3) a wash or plaster coat of neat cement or cement mortar, the former varying in thickness from $\frac{1}{32}$ inch to $\frac{3}{32}$ inch, used principally on brick walls, and the latter from $\frac{1}{2}$ inch to 2 inches; both applied either to an interior or exterior surface of concrete or other masonry. The cement mortar coating, again, may be composed of: (*a*) cement, sand and water mixed in any efficient proportion that will produce a dense and impervious coating; (*b*) cement, sand, water and a powder, paste or liquid waterproofing compound (usually of a proprietary nature) which is mixed in specified proportions for the purpose of producing similar or more impervious coatings.

The surface coating system of waterproofing is adapted to waterproof structures either during construction or after erection. It is applicable either to the external or internal surfaces of the structure, depending on the physical condition of the surface to receive the waterproof coating, the water pressure behind the surface, the kind of material used and the thickness of the coating to be applied. This method is comparatively cheap and has a wide application in spite of the few materials (other than proprietary ones) adapted for such coatings.

Amongst the oldest preserving processes in construction work are plastering and painting. Since paint forms an impervious coating easily and cheaply applied, it was utilized not only for decorative, but also for dampproofing purposes. It was a matter of general knowledge that linseed oil paints and varnishes, besides serving other obvious purposes, were also a dampproofing medium; that lime plaster and cement mortar, especially the latter, applied in comparatively thin coats, performed the same function. Hence the next step in the development of this system of waterproofing was to apply a coat of bituminous paint or a mortar coat, thick and dense enough for each material to act also as waterproofing. Eventually there came into use proprietary waterproofing compounds employed directly as surface coatings or incorporated in the plaster or mortar coat to increase its imperviousness.

The surface coating system of waterproofing is in common practice to-day, especially the mortar surface coat, because with it the

engineer encounters the least difficulties. The invention of the " cement gun " has made this possible more so than any improvement in the grading or proportioning of the ingredients for producing impervious mortar. The history of this invention is rather interesting. About 1895 Mr. C. F. Akeley, a taxidermist of Chicago, invented the cement gun for the special purpose of coating the framework of a dilapitated house with mortar to save it from destruction. This proved so successful that he coated other frame buildings by the same means. In 1911 engineers in the United States service in the Philippines experimented with a similar machine until they perfected it, and then used it quite extensively. Since then the cement gun has come in modified and improved form, into quite general use.

FIG. 4.—Applying Plaster Coat Over Bituminous Dampproofing Coat.

Methods of Applying Surface Coatings. There are three common methods of applying impervious coatings: (1) by brush, (2) by trowel, (3) by machine. All liquid compounds are applied with a brush (see Fig. 4), or paint-spraying machine, both processes being done in the same manner that paints are applied. When thus applied, the compound either forms a film on the surface or penetrates the surface of the mortar or concrete, and by capillary action is drawn further in to a depth varying between $\frac{1}{8}$ and $\frac{1}{4}$ inch (see Fig. 5), depending on the solvent, porosity of the surface and density of the mortar or concrete. As a plaster coat, the given waterproofing material is applied with a trowel by hand (see Fig. 4). In this process pressure and uniform motion are essential, but most essential is the continuity of the coating. As a mortar coat it may be applied

either with a trowel or with the cement gun. When the plaster, neat cement, or mortar surface coatings are applied with a trowel, as on the back of a retaining wall, the outside of a brick sewer or manhole, the inner face of a tunnel or swimming pool, they should be finished off to bear a smooth or granolithic face. The granolithic surface on these coatings, produced only by careful troweling, materially increases their imperviousness. The coatings should not be made too thin, as peeling, blistering, and cracking inevitably follow, especially if used where they are subject to atmospheric changes.

When mortar is applied with the cement gun, the coat can be made a very efficient waterproofing medium, provided the materials are properly used and proportioned. In no case should a leaner mixture than 1 : 3 be used and the best results will follow the use of

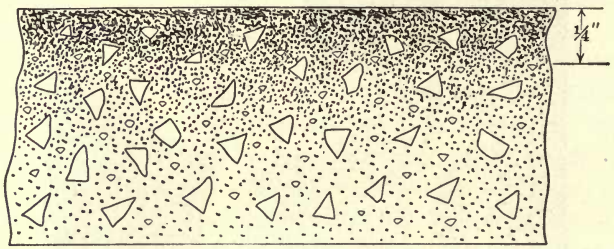


FIG. 5.—Ideal Penetration of Surface Coating.

a clean, somewhat moist and coarse, but graded sand in the mixture. In operating the cement gun (see Fig. 6) the dry materials are forced through a hose by means of compressed air, hydrated at the nozzle, and applied with any desired velocity. This velocity of approach of the mixture produces a considerable rebound of the sand, which is wasted; this leaves, however, the adhering mixture richer in cement. The combination of cement, sand and water which produces the plastic material, takes place in transit, i.e., the hydration takes place immediately before and during the placement; the chemical combination or initial set of the cement takes place in its final resting place. If the surface is floated immediately after placing, a smoother finish is obtained. Troweling, however, will not always increase the imperviousness of the mortar, and may even offset the good effects of floating, hence it should be practiced with great care or not at all. The technique of cement-gun applications requires thorough familiarity with the machine and proportioning of aggregate

before any important waterproofing work can be prosecuted successfully. Chapter VI contains a more detailed description of the modern cement gun.

Preparation of Masonry Surface Prior to Application of Coating. Before applying any of the dampproof or waterproof coatings, all masonry surfaces should be prepared by chipping off all skins of dried or hardened cement or other material, so that practically an entirely new surface is produced. It is best to do this not more than a few days prior to the application of the coatings. Chipping

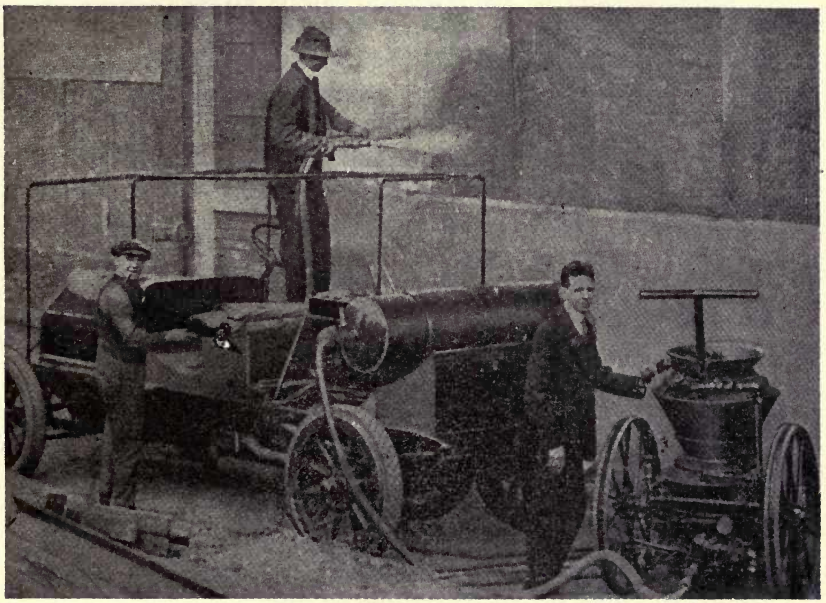


FIG. 6.—Applying Mortar Coat with Cement Gun. (Operated with Power from Automobile Engine.)

the surfaces will be facilitated and a much better bond secured by a previous application of muriatic acid of about 1 to 10 solution, the strength of the solution depending on the age of the structure to be treated. The acid should remain on the surface until it has exhausted itself. This will require about fifteen minutes. Then a second coat, and if necessary a third coat of acid solution should follow the first and be brushed in with a stiff wire brush. When sufficient aggregate has been exposed and the entire surface cleaned, all traces of the acid must be removed. This is best accomplished by a rigid application of water from a hose immediately after the

acid treatment has reached a satisfactory stage. This slushing, which should be done with perfectly clean water, should continue until all the salts (formed by the chemical action of the acid on the cement) are removed and the surface is free from acid. All holes, large or small, should be plastered up independently of the surface coating unless the coating is a waterproofed mortar.

Application of Slush, Scratch, and Finishing Coats. If the wall or other surface is not washed with acid it should at least be chipped and brushed, and just before the mortar coating is to be applied, the surface should be thoroughly drenched and soaked to its full absorbing capacity. Then, before the walls or other surfaces show marked signs of drying, a "slush coating" should be applied over the entire surface. To prepare this slush coat some of the mixed ready-for-use coating material may be thinned with water to the consistency of cream. It is then applied with a stiff brush, with a scouring effect, care being exercised to fully cover the inner surfaces of all crevices and holes.

Before the slush coating has dried, the first application of the regularly mixed coating material should be applied as a scratch coat, from $\frac{1}{4}$ to $\frac{1}{2}$ inch thick, and pressure brought on the trowel to push the coating on, and so obtain a uniformly thick layer, well bonded. The best practice is to trowel the scratch coat to a fairly good surface, and then to scratch criss-cross over the entire surface before it hardens. This insures a better bond for the finishing coat.

Upon the scratch coat, and before its final setting, a finishing coat of sufficient thickness to obtain the required thickness of mortar coat should then be applied. If this required thickness is more than $1\frac{1}{4}$ inches, the thickness of the scratch coat should be increased accordingly. The finishing coat, too, should be pushed on hard and uniformly troweled and floated to a true surface, free from pits, pin holes, sagging cracks, projections or other defects. The floating of the finished surface is best done from the bottom of the wall up. These instructions are applicable whether the coating contains a waterproofing compound or not.

In general, also, the surface of masonry to be waterproofed by the surface coating system of waterproofing should be cleared of any interference from timbers and temporary struts, because the presence of such false timbering interferes with the proper and continuous application of the waterproofing. If such false timbering is not readily removable, then the locations of struts and posts, etc., resting on or against the surface to be waterproofed, require very careful workmanship and close inspection to insure the proper and

complete waterproofing of holes left by removal or shifting of such false work on the completion of the construction in hand. This is especially true when such timbering is situated in poorly illumined and cramped areas. A method of overcoming these difficulties is explained in the article on the membrane system of waterproofing. Other means of procuring a continuous surface so as to avoid leaving unwaterproofed areas will suggest themselves as the occasion arises; the important point to remember is that every temporarily unsurfaced spot constitutes a weakness in the waterproofing system.

Materials Used for Surface Coatings. The materials generally used for surface coatings are: (1) neat cement, cement mortar, and proprietary cements, i.e., ordinary cements containing void-filling or water repelling substances; (2) finely powdered metals, as, for instance, powdered pig iron; (3) mixtures of soap and alum; (4) paraffin, either in liquid form, or in solid form, but melted, or in solution with petroleum oil or coal-tar naphtha; (5) patented bituminous products, i.e., mixtures of asphalt, linseed oil or wood oil and resin with some form of inert filler, as powdered or shredded asbestos; (6) proprietary liquid hydrocarbons, i.e., solutions of paraffin in benzine or benzol, or emulsions of petroleum oil and fat oil. Some of these can be applied to a wet or submerged surface (varieties of the patented bituminous products), but a dry surface is always preferable. The general properties of some of these materials are treated in Chapter V.

Practical but simple illustrations of the manner and method by which coatings are applied are shown in Figs. 4, 7, 8. Fig. 4 shows a brick wall below ground surface, coated with a liquid bituminous paint which in turn is surfaced with a treated (i.e., waterproofed) mortar. This process is most effective as a dampproofing rather than as a waterproofing. Fig. 7 shows a culvert arch waterproofed with a plastic, bituminous compound. Fig. 8 is a cross-section of a swimming pool waterproofed with a cement mortar coating. To this mortar was added a definite amount of a proprietary powdered metallic compound to increase its imperviousness.

Application of Cement Mixtures. In applying either neat cement or cement mortar, the engineer is not handicapped by lack of knowledge of the materials or results. The required information is readily obtainable with considerable certainty. However, when patented cements are used this is not true to the same degree. Experiments and experience have proven the waterproofing qualities of the former, but the same cannot be said of the latter. In fact, in many instances ordinary well-made and applied mortar will be more effective.

The United States Army engineers recommend the use of sand-cement for mortar coatings.* This cement is sometimes substituted for the natural, but Portland cement has been found to be the best to use for waterproofing purposes. For coating sea walls and other marine constructions, puzzolan or slag cement mortar is well adapted. For coating exterior concrete wall surfaces and interior surfaces of cisterns or tanks, and especially any masonry below ground-water level, Portland cement mortar in proportions 1 : 1 or 1 : $1\frac{1}{2}$ will create watertightness. The mortar should preferably be applied against the surface which is to come in contact with the water.

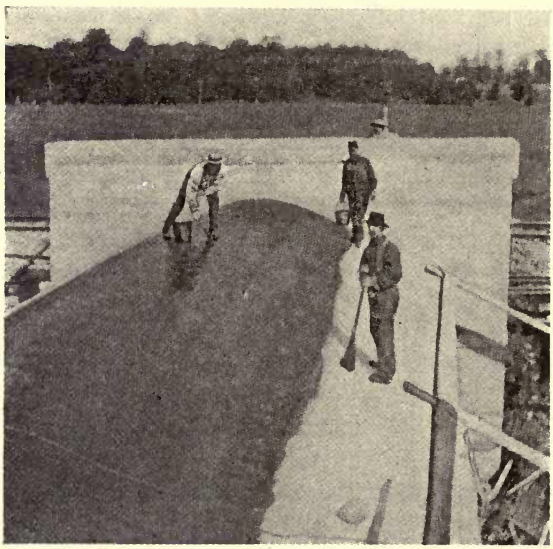


FIG. 7.—Applying Bituminous Coat with Brush to Arch of Culvert.

But where a good hold can be secured for the mortar and if made thicker than $\frac{3}{4}$ of an inch, it may be applied to the other side. In Table XXXII are given suitable thicknesses applicable to varying heads of water. Where imperviousness is desired both ways, both sides should, of course, be coated. Increased watertightness will be secured under all conditions, whether the mortar coat be applied by hand or machine, by troweling the surface to a granolithic finish. However, this granolithic finish must be produced with the greatest care, otherwise it will vitiate its purpose.

* Taylor and Thompson, "Concrete, Plain and Reinforced," 2d Edition.

Use of Lean and Rich Mortars. The use of lean or rich mortar is mainly dependent on the purpose each is to be put to. Mortar contracts on drying and expands on wetting, hence cracking invariably results. This is greatly reduced by reducing the proportion of cement, which alone is affected and causes the cracks. In stucco work or on other superstructural applications the leaner mortar is most advisable. The sand should be graded so that the proportion of medium-sized grains is small, and the coarse and fine grains are about equally mixed.

Experience shows, for instance, that a plain 1 : 3 stucco, properly applied, remains free from cracks, but is rather porous. A 1 : 2 stucco, however, while less porous, is subject to considerable cracking, unless well protected during the setting period. But such protection (i.e., protection against freezing, or exposure to the sun and quick drying out) besides being a good deal neglected, is often impossible.

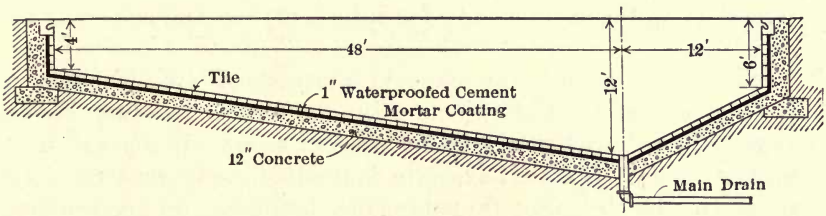


FIG. 8.—Swimming Pool Waterproofed with Waterproof Mortar Coat.

Hence it resolves itself to a question of how to make stucco mortar lean enough to avoid cracks, yet dense enough to be dampproof. This difficulty is often overcome by the use of a suitable integral waterproofing compound, or a surface coating material which evaporates slowly and leaves the surface pores filled.

Since the strength of mortar here is of least consideration, and absolute impermeability of the mortar of secondary consideration, (i.e., the mortar for stucco work need but be made dampproof) these waterproofing materials find a very good field of usefulness. But the indiscriminate use of such compounds as, for instance, soap and alum washes, caustic potash, stearin and resin compounds, or chloride of lime and other metallic salts, or, for that matter, any of the many waterproofing or dampproofing compounds, without test or careful investigation is unwarranted. The architect who specifies any of these compounds without investigating or experimenting (and all too many do so) to ascertain their value for this

particular purpose is wasting his clients' money and hazarding his own reputation. The many worthless and the few worth while compounds on the market make it imperative to search most conscientiously for a material that will not wash out after a few rain storms; that will not discolor or disintegrate, or induce disintegration; that will prevent hair checks and remain cementitious while creating imperviousness in the stucco, and that will not induce peeling or blistering of the stucco. Service and practical tests are the best, and in fact, the only means for determining the effectiveness of any of these materials.

In connection with the use of a large proportion of cement in mortar or excess cement in concrete, it must be borne in mind that the practice is wrought with many dangers for vitiating its ostensible purpose, i.e., increasing the density of mortar or concrete. For underground construction this practice is entirely warranted and efficacious, but for superstructural work of any sort this practice is successful only on the performance of the work with the most painstaking precautionary measures for curing, drying, and seasoning the structures.

Only a few of the many patented cements and bituminous paints on the market for waterproofing by the surface coating system possess the requisite properties for efficient usage. In general, these properties are: (*a*) That absolute dampproofness or waterproofness be effected by their use; (*b*) reasonable cheapness; (*c*) applicability; (*d*) durability. Experience and experiment have shown that only a very few of these special dampproofing and waterproofing compounds possess the same effectiveness as a moderately thick coating of neat cement or cement mortar, the latter of a maximum thickness of about 2 inches for the most adverse conditions.

Cement mortar, as ordinarily mixed, can be made practically impervious by the addition of alum and potash soap. One per cent by weight of powdered alum added to the dry cement and sand and thoroughly mixed, and about 1 per cent of any potash soap (ordinary soft soap) dissolved in the water used in mixing the mortar will make it remarkably impermeable, but the results are not lasting. A dry clay mixed with cement in equal proportions and applied as a coating is also effective as a waterproofing agent, provided any form of cracking is prevented.

A surface coat of cement mortar of a thickness and proportion best judged from requirements at hand, is sometimes used for creating a dry surface upon which to apply a different system of waterproofing.

The impermeability of plain cement mortar is well shown in Table III, which is adapted to our purpose from the United States Bureau of Standards, Technologic Paper No. 3.

TABLE III.—PERMEABILITY OF MORTAR OF QUAKING CONSISTENCY

Proportion by Volume of Portland Cement to Meramic River Sand.	Age in Weeks when Tested.	Cubic Millimeters of Water Passed per Minute per Square Centimeter of Surface Subjected to 1.4 km. (3.1 lb.) Hydrostatic Pressure.* Thickness of Test Pieces in Inches.		
		1	2	3
1 : 2	4	0	..	..
	8	0	0	0
	26	0	0	0
1 : 4	4	1.0	1.0	0
	8	0	0	0
	26	0	0	0
1 : 6	4	31.2	24.0	17.0
	8	.8	2.0	5.0
	26	1.9	.8	.5
1 : 8	4	149.0	324.0	749.0
	8	90.5	132.0	126.0
	26	9.0	9.0	43.0

* Average value of three test pieces tested for six hours.

Application of Powdered Metal. The waterproofing effectiveness of powdered metal, such as powdered pig iron or other iron oxide depends upon the barricading effect of its increased bulk due to corrosion while it is held in suspension in the gaging water, which, of course, permeates the mass. When mixed with the cement, which is the most usual way, the moist particles of iron oxidize and expand, thus filling the voids in the concrete mass; or, when applied to the surface of concrete, either as a slush coat or thin mortar coat, its action results in the production of a hard, dense, and impervious finish. The corrosion is often assisted by the addition, in very small quantities, of some oxidizing agent such as sal-ammoniac or sulphur. This same mixture is often used, under various trade names, as a concrete floor hardener. In fact, powdered metal finds its greatest usefulness in this field. When so used it should be floated on the surface and then finished off with a trowel. Success in the use of this material necessitates the employment of very careful and skillful

labor. Quantities and rules for applying powdered metal are usually issued by the manufacturers of these materials, and should be carefully followed.

The Sylvester Process. The use of soap and alum solutions for coating a masonry surface is known as the Sylvester Process of dampproofing and waterproofing. It is applicable alike to concrete and other masonry. It does not, however, form a permanent waterproofing, and is not much used at the present time. In using these materials the following precautions must be observed: (*a*) Each should be perfectly dissolved before being applied. (*b*) The masonry surface should be dry and clean before application. (*c*) The air temperature at the time of application should be between 50 and 60 deg. Fahr. (10 and 15.5 deg. Cent.). (*d*) The soap solution should be boiling hot and applied first, using a flat brush for this purpose. The alum solution is then brushed on at a temperature between 60 and 70 deg. Fahr. (15.5 and 21 deg. Cent.), thoroughly covering the first coat. An interval of one day should elapse between the application of each set of coats. The number of coats is dependent on local conditions, including water pressure and exposure to the elements.

The proportion of soap and alum giving the best results is $\frac{3}{4}$ pound of castile soap to 1 gallon of hot water; $\frac{1}{2}$ pound of common alum to 4 gallons of lukewarm water. The action is chemical. The two materials combine to form a stearate of aluminum, which fills the voids in the concrete and is insoluble in water. A solution consisting of 1 pound of concentrated lye, 5 pounds of alum, and 2 gallons of water, applied while the concrete is green and until it lathers freely, has been successfully used. A cheap and effective substitute is a mixture of 1 part of aluminum sulphate and 3 parts of hard soap, by weight. This may also be used as an integral compound, in proportions determined by experiment, for mass mortar or concrete.

Application of Paraffin. The application of paraffin is universal and adapted to all classes of masonry above ground. If applied cold it is specially treated, e.g., it is boiled to rid it of water, the presence of which renders it difficult to apply, and dissolved in a highly volatile compound. Being an almost colorless, translucent liquid, it does not change the color of the surface to which it is applied. It is easily applied with a stiff flat brush, and the best results are obtained by thoroughly rubbing it into the surface, using three coats if the surface is rough. If the surface is clean and smooth, two coats are sufficient, because the solvent has a high penetrating

capacity, by which function it leaves the pores filled with paraffin after the volatile matter has evaporated. Most paraffin compounds are prepared for use by the manufacturer, who usually issues directions for their application, but ordinary commercial products may be used. In general, however, the following precautions should be observed: (1) The surface treated should be made smooth and dry, the first by chipping all projections and rubbing with a stiff wire brush if necessary, the second by doing the work after a dry period. (2) No fire should be near the material when applied, because the volatile solvent is very combustible.

If the paraffin is to be applied hot, it is merely melted and thoroughly rubbed into the surface, which has been previously prepared and warmed, to be waterproofed. The latter is most economically done with improvised salamanders, using charcoal as fuel. If dissolved in the proportion of one-third paraffin and two-thirds kerosene, it remains soft longer and penetrates the stone further. Paraffin is the very best waterproofing material for exposed work of all kinds, but needs to be applied by men experienced in this work. With a sufficient penetration, durability and effectiveness is assured because of the natural inertness of the paraffin.

Application of Bituminous Compounds. There are many bituminous paints, pastes, and enamels offered by manufacturers for use in the surface-coating system of waterproofing. Compounds of this nature are also used for dampproofing. When used for this purpose, the film or coat is usually applied somewhat thinner than for waterproofing. For the latter purpose, the film or coat does not exceed $\frac{1}{4}$ inch, except when the material is a bituminous mastic, in which case it is applied in thicker form. If employed as dampproofing for exposed walls of buildings or other superstructures, these bituminous compounds are usually applied on the interior or between wall surfaces. As waterproofing, these compounds are applied either on the exterior or interior surfaces of underground works, depending on conditions. In structures already erected some of these compounds are well adapted to remedy leaky conditions because they can be applied on the inside and sometimes to a moist surface. This obviates the expense of excavating around the foundation. Allowing bituminous waterproofing materials to remain in direct contact with earth or other backfill, i. e., unprotected, is poor practice because the acids or alkalies present in the backfill will eventually destroy such materials. Bituminous coatings are sometimes applied to the inner surface of foundation walls and tunnels even where a water pressure exists, but they are not dependable to withstand

this condition unless backed up with an inch or two, or more, of cement mortar or concrete, and the work done with care.

A priming coat should always be used before applying liquid bituminous surface coatings to waterproof a structure, and in this connection field engineers and inspectors will do well to guard against the following practices: (1) Failure to apply a continuous priming coat; (2) the use of a viscous material as a priming coat. On certain construction work, especially municipal work, it is often to the advantage of the manufacturer or his agent to supply material of the same consistency for the priming coat as for the other coats, because very much more of it is required for the first than for the succeeding coats on account of the usual roughness of the surface. The waste of material, however, is the least objectionable in this case. The serious nature of such practice lies in the failure to utilize the priming coat for what it was intended to accomplish, namely, to enter the surface pores of the concrete or other masonry, to find every little depression or small hole and coat it, and to assure the adhesion of the coats which follow. These objects are not well accomplished by using a viscous material for a priming coat. The right consistency of a priming coat is one as liquid as water or milk, in which state it can penetrate deeper below the surface.

The composition of most surface coating compounds is kept secret by the manufacturer, and the only real safeguard one has in purchasing them discriminately is to observe the results on structures already waterproofed with any of these products. In general, the following precautions should be observed when buying and applying such materials: (1) Chemical test on a representative sample of the material should show (*a*) preponderance of bitumen, (*b*) resistance to acids and alkalies, (*c*) strong adhesion to concrete or other masonry, (*d*) toughness at low temperatures. (2) Results of tests on representative specimen should be checked with material as received and then applied according to the manufacturer's directions. (3) The surface to be waterproofed must be made clean and dry, applying not less than two coats; the first coat, usually a primer (that is, the same material, or ordinary asphalt or tar, thinned to a more liquid consistency) is allowed to become dry or nearly so, before the second is applied. (4) Great care is required (*a*) to obtain a continuous film of coating, (*b*) to fill all corners, recesses and depressions, (*c*) to leave the final surface roughened, yet coated, if a plaster or mortar coat is to be applied directly on the film, (*d*) not to injure the film in applying these coats, and (*e*) not to expose the applied material unduly.

Straight-run coal-tar products are often and successfully used in the surface-coating system of waterproofing. For example, in protecting abutments and retaining walls from disintegration due to their natural permeability, various dampproofing bitumens are successfully and cheaply made and applied, of common creosote oil and coal-tar pitch. The creosote oil is applied first and penetrates the wall to a degree depending on its quality and the density of the masonry, and this is followed by at least two moppings of the coal-tar pitch. In some instances where the concrete is very porous, a third and fourth mopping may be required in order that the entire surface may be well covered. Dull spots on the surface are evidence that the pitch has only penetrated into the pores of the concrete but the outer surface is not completely coated. A mixture of coal-tar and powdered slate of the consistency of molasses is often used for similar purposes. Occasionally, a 2 or 3-ply felt- and pitch-membrane is applied to such structures.

Instead of the tar products, refined asphalts of good grade may be also used. Where a first or priming coat is required, and it is practically always advisable to apply one, this usually consists of asphalt diluted in naphtha or gasolene. Of course, both the pitch and asphalt must be of a consistency and melting-point to withstand the local climate or special condition of the work. Either of these materials will be benefited by a protective coat of some form, especially when this waterproofing is in the form of a felt or fabric membrane. A bituminous paste composed of chinawood oil, asbestos and pine tar is well adapted for such and similar purposes, but its consistency and application must be carefully watched. Coating the surface with boiled linseed oil until the oil ceases to be absorbed is another method that has been used with success. In Chapter IX are to be found various formulæ of compounds usable for dampproofing and waterproofing purposes.

Membrane System of Waterproofing

Definition, Purpose and Development. The membrane system of waterproofing refers to: (1) a built-up, elastic, continuous bituminous blanket or membrane composed of one or more layers of waterproofing felt or fabric cemented together with asphalt or coal-tar pitch, and which more or less completely surrounds the structure waterproofed; (2) metal linings, which usually also constitute an integral part of the structure, as in steel-plate or ring tunnel

tubes* wherein the metal lining is protected within and without by masonry. (3) Any method or material which permits the more or less complete enveloping of a structure to prevent the passage of water through its exterior parts, but which is itself not in direct contact with the water, that is, which is itself protected by some other covering. Such protective covering may be of concrete, vitrified hollow tile, or brick in cement mortar and sometimes a layer of mastic.

The purpose of the membrane system of waterproofing is principally to waterproof structures in course of erection, particularly those below ground surface, such as subways, tunnels and building foundations; but it applies equally well to retaining walls, arches, reservoirs, etc. It is not so well adapted to the waterproofing of structures already erected or to remedy leaky conditions developing subsequent to erection, owing to the fact that the membrane must be applied to the outside of the structure, thereby usually necessitating considerable excavation.

In the very earliest times, asphalt was used simply as a surface coating, that is, to serve as dampproofing. In this condition it was not well adapted to resist water pressure, even when placed between two masonry surfaces. To overcome this defect, fibrous paper was introduced between these surfaces, with a coating of bitumen on either side. For greater water pressures, the number of plies of paper was increased, each being coated with bitumen as applied. Paper was gradually superseded by waterproofing felt; this was largely composed of rag and wool, or pulp. The wool variety of felt has had until comparatively recent times a very extensive use, but because of the unreliable quality of wool purchasable now, and to an extent, its high cost, rag felt and pulp felt are now more commonly used. These felts are now in sharp competition with cotton and jute fabric. Commercially, refined asphalt and coal-tar pitch have been used for a long time in connection with the treatment of paper, felt, jute and cotton fabric, and also as a binder for forming waterproofing membranes of these materials. Now there is sometimes incorporated in these bitumens mineral fillers, such as shredded asbestos for instance, for the purpose of increasing their plasticity and substantiality

Applying the felt or fabric membrane to a structure calls for certain precautions which can ill afford to be neglected. These pre-

* Metal linings or castings may be used anywhere, but especially where great stresses are anticipated or where it is practically impossible to apply the ordinary membrane. This type of construction, however, requires special design for each case.

cautions are embodied in three fundamental requirements to be carefully observed in order to insure good waterproofing by the membrane system. These are (1) surface preparation; (2) continuity of membrane; (3) protection of membrane.

Surface Preparation Prior to Application of Membrane. It is impossible to make a bituminous sheet adhere properly to a wet or rough masonry surface, but it is advisable to make it adhere to whatever surface it is applied. The surface to be waterproofed should, therefore, be prepared by chipping all projections and smoothing off with mortar and trowel all depressions; cleaned by sweeping or scraping off all foreign matter of whatever nature; dried (when waterproofing must proceed during rainy weather, or before the concrete has completely dried after setting), by heating the surface, if not large, with a gasoline torch, by burning gasoline on the surface to be waterproofed, or by employing salamanders; or again, by providing a temporary drainage system that will keep the surface dry during the application of the waterproofing. If these measures are impracticable or insufficient, then one or two plies of felt, with the first laid dry, that is, without a bituminous binder on the under side, and nailed to or against the wet surface, if necessary, will create a dry area for the application of the waterproofing proper. Where it is difficult or impossible to apply this dry-ply, as on arches of tunnels, a thin sheet metal lining nailed to the masonry, or a cold application of asphalt dissolved in naphtha, or a reasonably thick plaster coat of neat cement or mortar, provides a dry surface on which to start waterproofing. Of course the concrete in all cases must be thoroughly set before any waterproofing is applied. As an illustration of how such problems are met in practice, may be cited the following instance.

In building the east face of the south Manhattan shafts of the Pennsylvania Railroad tunnels,* preparations were made to place the felt and coal-tar pitch waterproofing in the ordinary way, but it soon became necessary to drain away water that was running down over the face of the wall from the exposed rock above. To accomplish this a drain was constructed on the face of the wall near its top. This consisted of a strip of tin set in a ridge of plaster of Paris stuck on the face of the wall. The drain had a slight grade downward. It answered the purpose very well, allowing the wall to dry out below the drain. This type of drain was found useful at many points, because it could be applied quickly and at small cost.

* Transactions, American Society Civil Engineers, Vol. 69, p. 80.

Necessity of Continuity of Membrane. Continuity of the membrane is more important than the preparation of the surface to be waterproofed, for it is not always necessary to make the membrane adhere to a surface as long as the sharp projections have been removed and a reasonably smooth surface obtained; but lack of continuity creates a condition directly opposed to the purpose of waterproofing; for water will find the break, large or small, percolate through it, and be a source of annoyance at first and danger at last.

The continuity of a waterproofing membrane may best be secured by breaking joints systematically and leaving sufficient lap to form a good connection with the adjoining section. In applying the bituminous binder it is necessary to avoid blowholes, "dryspots," and other common defects. But these dangers are partly obviated by the very method of building up a membrane (see Fig. 14). In using either felt, fabric or cotton drill for this purpose, such defects will be greatly reduced by lightly pressing into the hot binder, which, incidentally, prevents "kinks" and also insures better adhesion between successive plies as well as to the original surface. Where the fabric is of the open mesh variety, the formation of air pockets between successive plies is automatically prevented, and pressing it into the binder will insure the filling up of all the interstices of the fabric.

Where a connection is made between a wall and roof of a structure, the lap should be about 1 foot wide. The successive plies of the membranous mat forming the lap on the wall should be interwoven with those of the roof mat and stuck fast against the side of the wall with binder. In joining the floor membrane with that on the wall, the latter should be interwoven as shown in Fig. 9A, with the lap ends of the floor membrane turned up an amount depending upon local conditions, but never less than 6 inches.

One of the most important matters in regard to the continuity of the waterproofing membrane, and one requiring careful attention, is the joining of new work to old. The old waterproofed surfaces, or the old laps, should be cleaned of all foreign matter, and, where necessary, softened by heating, as explained in "Surface Preparation." Such laps should receive a coat of bituminous material before the new strips of fabric are applied and pressed down as previously explained. Where possible, a mesh joint should be made of the laps of the old and new fabric as the plies are laid up. After long exposure of a portion of a membrane or its end lap, as on an uncompleted portion of work, the felt or fabric may have deteriorated or have been torn off. It is absolutely necessary to

provide sufficient lap width to properly join the old and new waterproofing; hence the safest expedient is to recoat the membrane with a thick binder film in the first instance, and to cut back at least 6 inches of the concrete or other masonry to secure sufficient lap in the second instance.

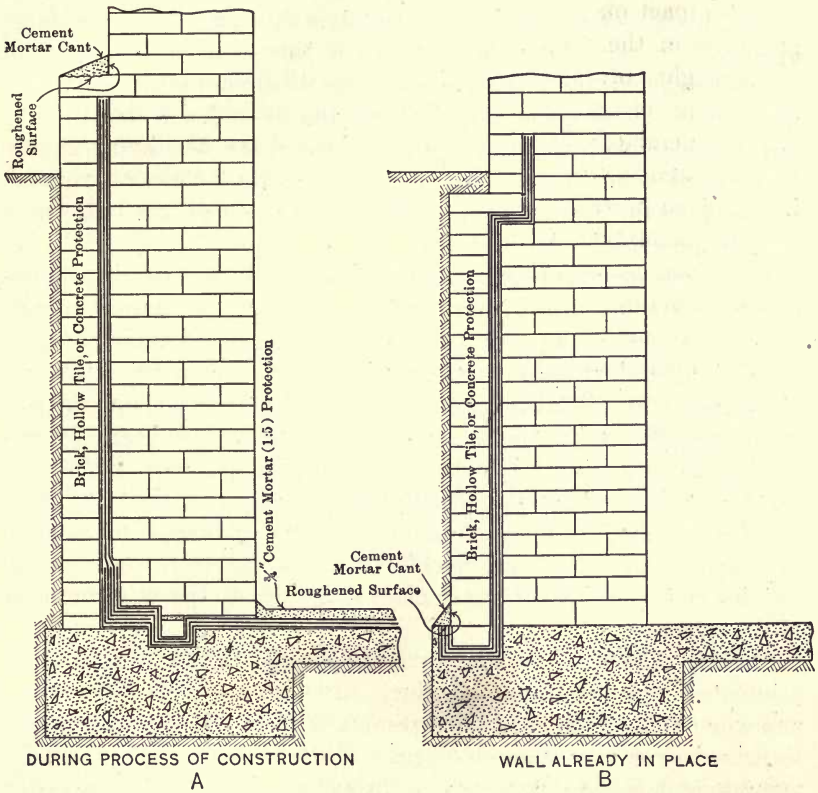


FIG. 9.—Methods of Applying Membrane Waterproofing to Walls and Footings.

Protection of Membrane. The third fundamental requirement of the membrane system of waterproofing is the protection of the membrane during construction, but more particularly after. During construction the waterproofing membrane may be injured by the workmen carelessly throwing about iron tools which sometimes puncture the membrane. The placing of temporary struts on the membrane may have a similar effect. Dumping of bricks and the unrestricted hauling of material, or walking on the membrane is particularly harmful to its continuity. A waterproofing membrane

applied to vertical masonry tends to sag and produce a rippled surface, especially in warm weather or when a particularly soft binder is used. In fact, no bituminous membrane, no matter how well applied or what binder is used, will stand up completely intact without support of some sort under such conditions.

After construction the waterproofing membrane may be injured by the impact of stones in the backfilling material, or by the large aggregate in the protective concrete if this is deposited from an undue height; or by bulging and running of the bituminous material due to heat, or cracking and chipping due to cold. Where there is any considerable hydrostatic pressure behind the membrane it may be perforated in a weak spot, or where a slight bulge or "ripple" has occurred in it, the added weight of the water on the bulge may drag the membrane down.

A serious menace to bituminous membranes surrounding underground structures arises from leaks in gas mains and sewers in city streets. All gas mains collect a kind of a pungent oil called gas-drip, which frequently comes out of leaky joints in the mains, saturating the ground over considerable areas. This oil will, in a comparatively short time destroy a portion of a waterproofing membrane by dissolving the bituminous binder, and, where felt is used, turn it into a soft, mushy and worthless material. Then again the membrane may be attacked by lubricating oil and other solvents from leaks in underground pipes or from machinery, as for example, where switch pits for surface railroads are in close proximity to the waterproofing of the structure.

Nearly all sewers, besides carrying sewage (which is sometimes acidulated and sometimes alkaline), carry steam and other gases, and where leaks occur, which happen quite often, the ground becomes saturated over a considerable area. The deleterious effect on the membrane in this instance is quite the same as in the case of gas-drip or oil, but not so marked.

Again, if a membrane is injured in any way, then the worst and perhaps the only serious drawback of the membrane system of waterproofing is encountered. The leak in the membrane is usually inaccessible from the outside without costly excavation, and cannot be gotten at on the inside except by removing considerable masonry. But what is still worse, it is almost impossible to tell where to begin excavation or tearing out the inner masonry, due to the fact that water is likely to travel a long way between the membrane and the wall so that the location of the leak or leaks on the inside may be as much as 150 feet from the injury in the membrane. This, incidentally,

emphasizes the need for making the membrane adhere to the structure.

To avoid possible injuries to the membrane during construction due to the causes mentioned above, temporary protection should be provided according to circumstances; for example, on the floor of a structure, by laying a gang-plank or enclosing the area with an improvised board fence; or if on a wall, by bracing strips of wood against it, especially to hold up the loose lap of the membrane and not allow it to dangle. Other expedients will suggest themselves as the need arises; the important thing to remember is that any properly designed protection will greatly minimize the above dangers.

After construction there should be placed on or against the waterproofing a protective coat of metal at the most vulnerable points,

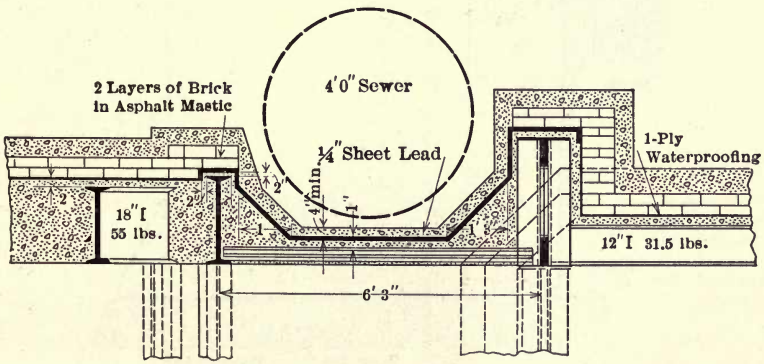


FIG. 10.—Roof of Ventilating Chamber Waterproofed with Sheet Lead Membrane.

and a protective coat of cement mortar or concrete, 2 to 4 inches thick, over the rest of the waterproofing. Fig. 10 shows one way of avoiding these dangers, by substituting a sheet lead trough for the regular waterproofing between a sewer and the top of a bay over a subway ventilating chamber. The protective concrete should preferably be reinforced, though this is not always necessary. A course or two of bricks, or a wall of flat or hollow terra-cotta tile are also good protective mediums. On horizontal surfaces, the hollow terra-cotta tile should not be used. The 3- or 4-inch concrete protective coat is the best in most instances because it is the least pervious. But in all cases the protective medium should be complete and cover every inch of membrane, and not as shown in Fig. 11 or Fig. 12A. Fortunately engineers are fast learning the folly of such malpractices as are depicted in these illustrations.

Then again, in protecting waterproofing membranes or surface coatings, insufficient consideration is often given to the end laps. Yet it is no less important and necessary to protect the ends than the rest of the membrane or surface coating. It should also be observed that in placing the protecting covering of whatever material, it is of primary importance not to make water seams of construction joints; in other words, joints in protective coverings or layers should be made to offer the greatest resistance to the passage of water. A case in point is well illustrated and self-explained in Fig. 12 wherein the conditions referred to here are manifested in a striking

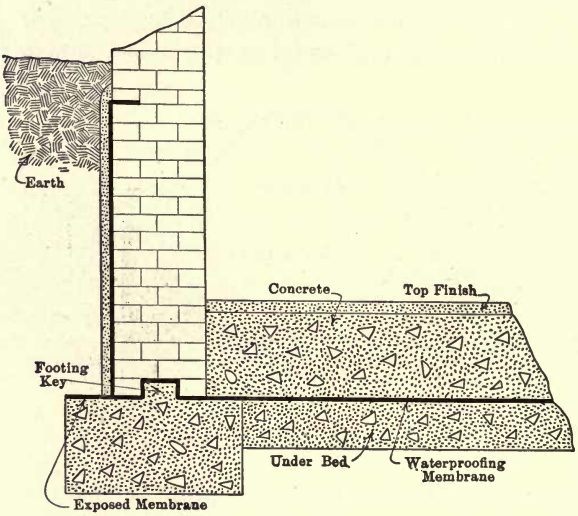


FIG. 11.—Application of Waterproofing Membrane with Insufficient Protective Coating.

way on a very important work. The improved methods of protecting such ends are simple, easily constructed in the field, and cheap from every point of view. A waterproofing membrane of any material or a surface coating of bituminous material will last very much longer and render better service when properly protected. In fact, even a 1-inch mortar coat is remarkably effective in this direction, and is sometimes used even on bridge floors. But, in general, for railroad bridges, which are subject to considerable vibration, a sheet mastic of about this thickness is preferable.

It is best to place the protective medium not later than one or two days after the waterproofing is completed. Where concrete constitutes the protective medium, it should be poured from the

least height possible, as depicted in Fig. 13. Also, in depositing heavy backfill on or against such a comparatively thin layer of concrete, care and judgment must be exercised not to break or

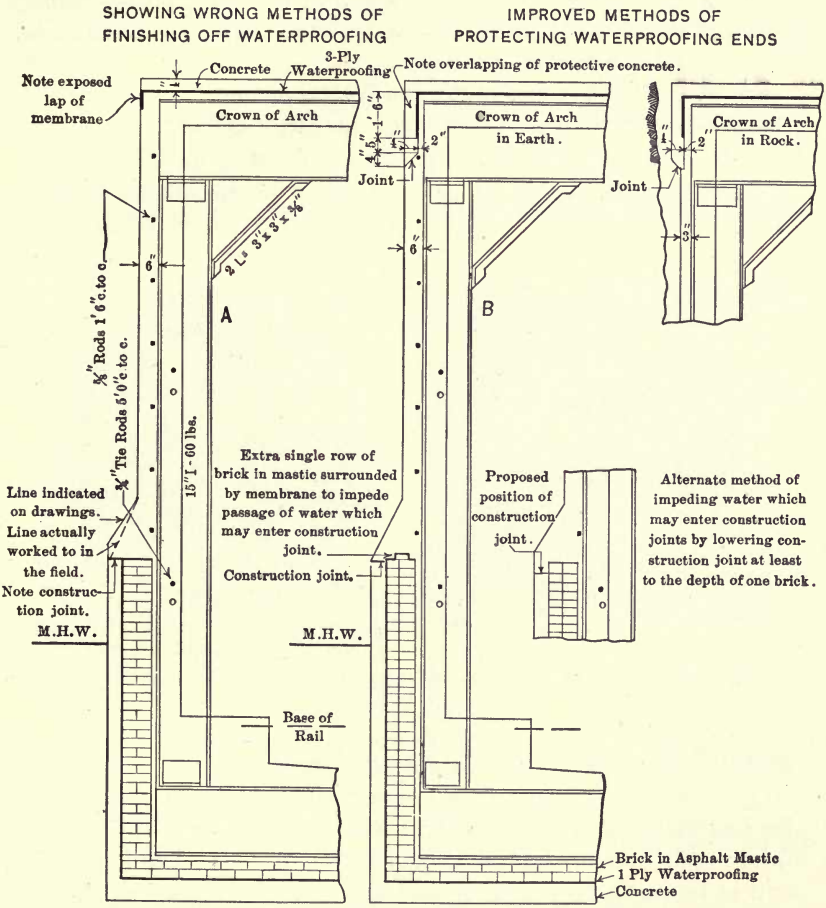


FIG. 12.—Good and Bad Practice in Membrane and Brick-in-mastic Waterproofing.

crush it. A practical and instructive illustration of this danger is given in the following instance:

On the New York Terminal of the Pennsylvania Railroad Tunnel Extension, the protective cover over the waterproofing membrane was designed to be of plain concrete from 5 to 6 inches thick. As long as the backfilling was kept well back of the completed work

and was stepped off in bench formation, the plain concrete cover served its purpose; but in one case, when the backfilling was advanced in bank formation close upon the completed construction work, the concrete cover broke and the waterproofing was damaged, requiring the removal of much backfilling to effect proper repairs. After this occurrence, the cover was reinforced with wire cloth and no further trouble was experienced.

Methods of Applying Membrane Waterproofing. In applying the membrane to any masonry surface, the latter is first mopped with bitumen, then the first strip of felt or fabric is unrolled thereon, tightly stretched, smoothed, and pressed into the film of bitumen. This strip is best made continuous over the width or length of the

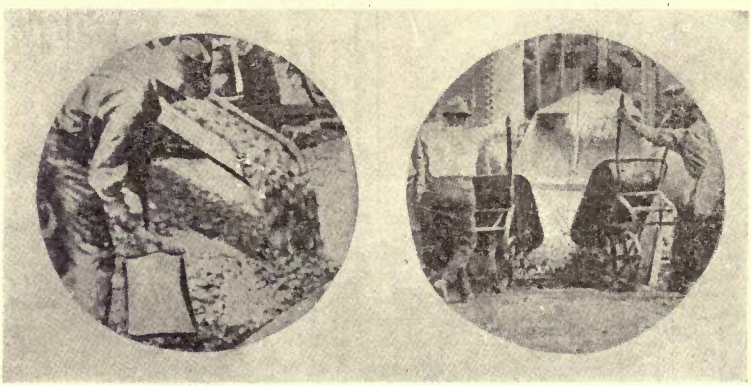


FIG. 13.—Height from which Protective Concrete Should be Poured on Waterproofing Membrane.

structure where possible. In this "continuous type" the second strip is laid to break joint with the first in a manner depending upon the number of plies used. The various methods of building up a waterproofing membrane are shown in Fig. 14. The portion of each strip of fabric to be lapped should be carefully mopped as the next strip is laid over it. When several strips have thus been laid, the second ply is similarly laid, then the third, fourth, fifth and sixth plies, as required. As each strip is laid or applied, it is important to see that no kinks have formed at the lap joints, for this leaves an opening for water to enter either between or under the membrane. The top ply should always be mopped completely over the entire surface, leaving no bare spots or other imperfections. See Table XXXII for the number of plies necessary to resist various heads of water up to 42 feet.

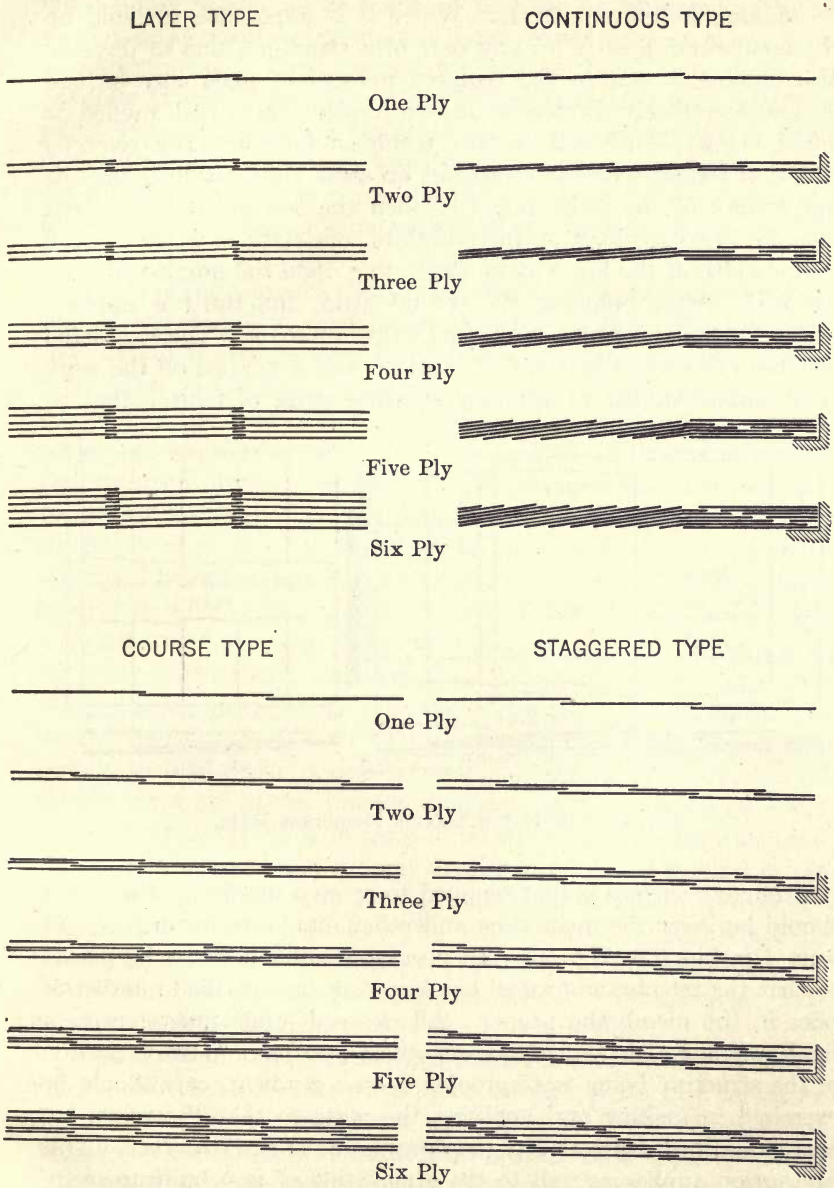


FIG. 14.—Four Methods of Building up Waterproofing Membrane. Applicable to either Felt or Fabric.

Making Membrane Mats. Where it is impossible to build up the membrane directly on any part of a structure, due to physical obstructions, a mat of the required number of plies may be laid up and completely formed in any convenient place and applied as noted below. This mat is best made as follows: The required length of felt or fabric is rolled out on some clean surface, and the top surface of the strip mopped; then the second strip is placed thereon, breaking joint at the one-third, one-sixth or other portion of the width of the lower strip, depending upon the number of plies required. After mopping the second strip, the third is applied, making an equal lap with the second strip, and so on. The completed mat then receives a top coat of bitumen and is applied on the work in a manner similar to applying separate strips of fabric; that is,

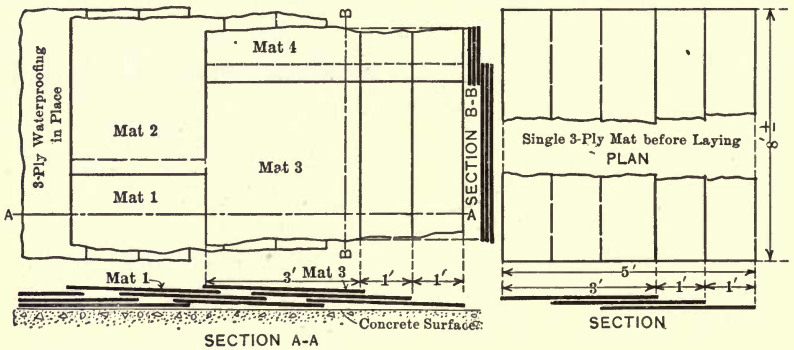


FIG. 15.—Method of Making Membrane Mats.

the concrete surface is first mopped to receive the mat. Each mat should lap over the membrane and other mats already in place, at least 4 inches (see Fig. 15). In no case should the mats be placed so that the membrane formed has less than the specified number of plies in the membrane proper. All exposed joints must receive a final mopping and be made as smooth as possible. When a portion of the structure being waterproofed is on a gradient, care should be exercised in making and applying the mats so that the joints lap each other in the direction of the down grade of the structure. This precaution applies as well to the application of any built-up membrane, whether vertically or horizontally applied.

Connecting New and Old Membranes. Joints form the weakest part of a membrane; therefore too much care cannot be exercised in making a joint between an old and new membrane by a proper

lap. Joints should be so made as to form as little bulge in the membrane as possible, but no butt joints should be used on any form of waterproofing. Laps exposed for any length of time should be carefully examined for any defects before connecting up, and where any defects or insufficient lap areas are found, the concrete or other masonry should be cut back sufficiently to give a proper lap between the sound membrane in place and the new work. Laps should not be less than 4 inches wide for each strip of fabric, or in any case not less than a total of 1 foot.

Timbers and temporary struts interfering with the proper application of waterproofing membranes present peculiar difficulties, and their locations require very careful workmanship and close inspection. The best method to insure the proper and complete waterproofing of the holes left by the removal or shifting of such false timbering, especially when they are located in poorly illumined and cramped areas, is as follows: All posts, struts or other temporary supports, whether on a floor or roof, or against a wall, should be shifted so as to avoid breaking the continuity of the membrane, otherwise holes are left not waterproofed. Where it is impossible to so shift these posts and holes must be left in the membrane, then it is necessary to paint these posts red or white, or otherwise to distinctly mark them, in order that they may be identified later when removed and the space occupied by them waterproofed. In waterproofing the space left by the removal of a post, or other support, a strip of fabric is cut to a size not merely sufficient to completely cover the space, but large enough to lap 2 inches on every side of the waterproofing in place as illustrated in Fig. 16; this total area is then mopped and successive plies of fabric are applied in the usual manner. Each strip should extend with a 2-inch lap over the one directly underneath it. The entire patch should then be thoroughly and heavily coated with bitumen. In no case must the fabric be cut to fit only the space occupied by the opening. Prepared mats fitted into the hole is also poor practice.

Placing Membranes around Projections and in Vicinity of Steam Pipes. Where pipes or rods project through parts of a structure that are to receive the membrane waterproofing, it is very important to make an absolutely watertight joint around these objects. These joints are best made as follows: As the first ply of felt or fabric is applied or laid against the surface, a hole should be cut in it fitting snugly around the previously cleaned and mopped pipe or other projection. Then a fairly large strip of felt or fabric, as the case may be, is placed completely around the object so that half adheres

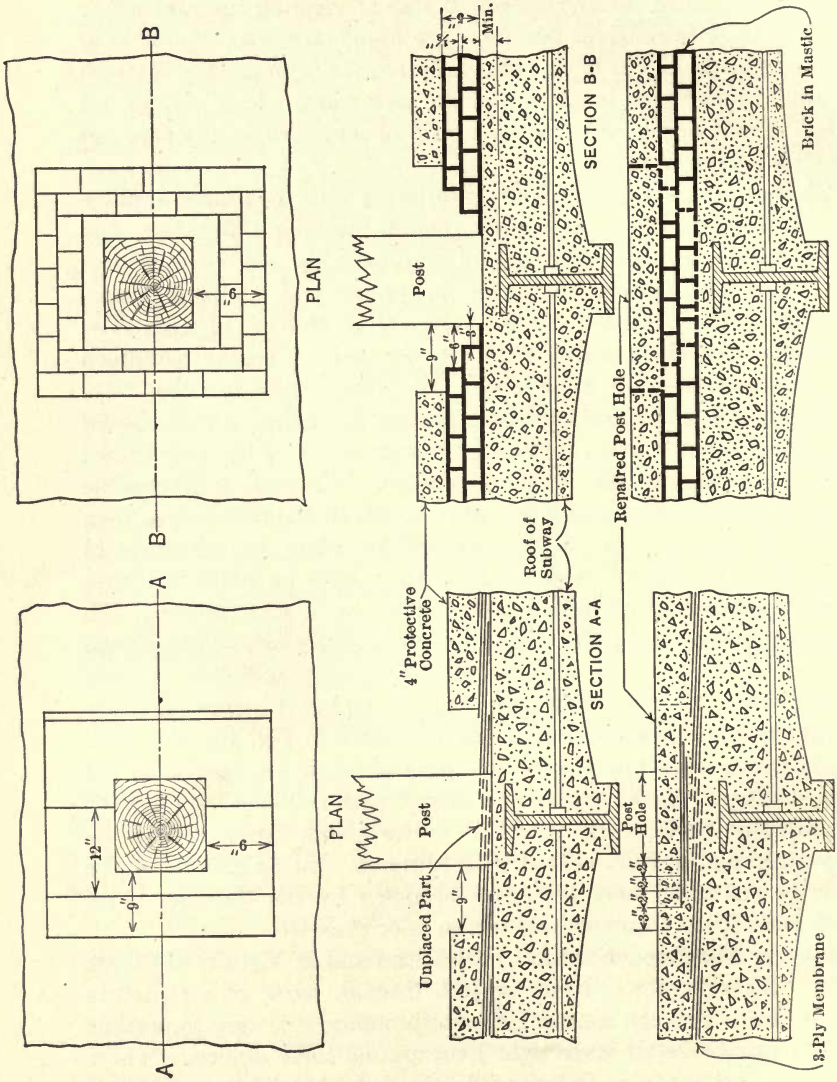


FIG. 16.—Methods of Waterproofing Post Holes after Removal of Temporary Shoring or False Timbering over Roof of Subway.

to it and the other half slitted radially adheres to the first ply on the wall or other surface. The successive plies are laid in the same manner. A finishing ply is then placed covering the slitted fabric and this ply is cut only to allow the pipe to pass through.

Satisfactory and permanent waterproofing in the vicinity of steam pipes is difficult to obtain. This may be accomplished, however, by placing a strip of sheet lead of sufficient length and width, and about $\frac{1}{8}$-inch thick, between the waterproofing and the supporting material of the steam main. It is understood, of course, that the main itself is first adequately insulated to prevent its radiating heat from affecting the waterproofing. A satisfactory method for insulating steam pipes is to surround them with a blanket of ten or twenty plies of untreated asbestos felt, encasing this with large semi-sections of vitrified sewer tiles, and packing the space between the two with coarse asbestos fiber. The whole must be well supported on concrete or vitrified two- or four-way tile ducts or other suitable non-conductive material, all depending on the size of the steam main, location and working conditions.

The above expositions are general. Modifications will often be necessary on such structures as railroad bridge floors, reservoirs and buildings, but the fundamental principles are the same. Hence, it is not necessary to consider here how each kind of structure is to be waterproofed. The main point to remember in regard to all types of waterproofing and all manner of structures is to suit the waterproofing to the structure, taking all local conditions in to consideration, including climate, purpose and type of structure. In the majority of cases, it may here be noted, successful and durable waterproofing depends not only on conscientious labor, but more particularly on expert supervision.

Use of Special Membranes. A modification of the usual long-strip, built-up, elastic type of membrane consists of a membrane made up of small, square layers of cotton fabric,* thoroughly saturated and heavily coated on both sides with a suitable bitumen and often with a special, that is, a proprietary bituminous compound. The cotton fabric commonly used has a thread count of 66 by 44 per square inch, weighing about $4\frac{3}{4}$ ounces per square yard. When treated, the fabric has an average thickness of $\frac{1}{8}$ inch, and weighs about $4\frac{1}{2}$ pounds per square yard. The operation of saturating and coating the strips of fabric is done in the field immediately adjacent to the work because the compound used must possess considerable adhesiveness so as to stick well to the applied surface

* Developed in 1907 by Oscar Sheffield, and in practical use since 1909.

and to itself when lapped to form the membrane, hence it is impracticable to handle the finished sheets between the factory and the field work.

The treated sheets, which are best handled when about 1 yard square, are laid over the surface to be waterproofed with not less than a 2-inch lap. The laps are then sealed with a hot smoothing iron to insure perfect adhesion, after which they are recoated with an additional layer of the bituminous compound. The membrane is laid so as to be continuous and unbroken over the entire area waterproofed. See Fig. 17. The protective masonry is then applied as on the built-up membrane.

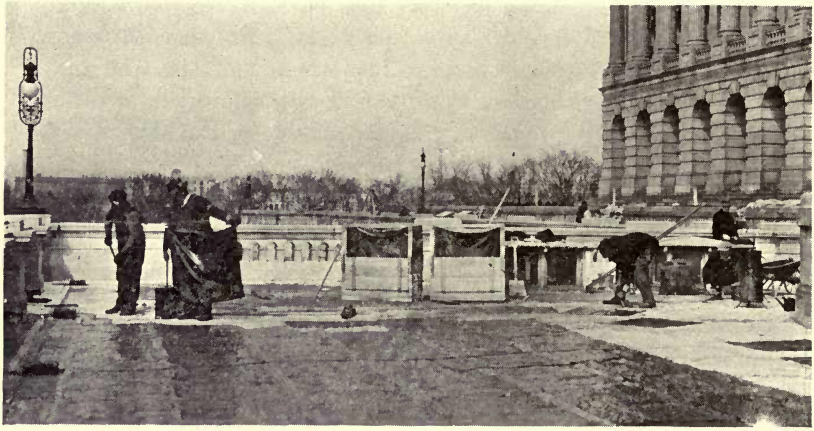


FIG. 17.—Applying Treated Cotton Fabric.

Any good quality of cotton or jute fabric is suitable for this type of membrane, but only a strongly adhesive, tough and elastic bitumen, and one that will remain plastic at all seasons, can be used satisfactorily for this purpose. At the present time only one proprietary compound is extensively used for this modified membrane. This compound consists of several hydrocarbons, each possessing different physical properties but mixed in proportions to secure the desired consistency.

Considerations for Selecting Membrane Reinforcement. The following question often arises in waterproofing design: What reinforcing material is best adapted for the membrane system of waterproofing? In other words, is treated felt, jute fabric or cotton drill to be preferred, and under what conditions or for what types of

structures is each best suited? This can best be judged and answered from experience. Felt was used extensively on the old Manhattan subways in New York City, in the form of a membrane composed of six plies of felt and seven coatings of asphalt, surrounding the structure like an envelope. But it has not given entire satisfaction apparently because this type of membrane has insufficient tensile strength, so that when cracks developed in the concrete shell, it too would break somewhere. Had this membrane been reinforced with two or three plies of jute or cotton fabric, this fault would not be operative in producing leaks. Then again, the felt in the membrane forms a stratified sheet with as many laminations as there are plies used. This creates many surfaces where water may creep along under certain conditions, and cause damage. Its close texture also prevents the escape of entrained air during its application, which tends to create air pockets between the plies. Besides, there is also present the capillary action of the felt fibers, though this is not peculiar to felt alone. It has, however, a very extensive and successful use on all manner of structures notwithstanding, and is cheaper per unit of area than either cotton or jute fabric.

Jute fabric, on the other hand, such as was used on the new Dual Subways in New York, also in the form of a membrane (composed of three to six plies of fabric with from four to seven coatings of coal-tar pitch), has thus far given entire satisfaction, and apparently for the following reasons: The fabric being of the open-mesh variety (and only such was used), permits the bonding of successive plies, thus forming a unit-membrane of bituminous material with the fabric acting as so much reinforcement. The open mesh automatically prevents the formation of air pockets between the plies. This fabric has considerable tensile strength and can easily stretch, without tearing, over ordinary cracks. This allows the bitumen to heal on favorable occasions. There is also somewhat more bitumen present in this membrane than is ordinarily present in a felt membrane of an equal number of plies. Tests by the author have proven that jute fabric can be thoroughly saturated and coated with either asphalt or coal-tar pitch, and when so treated is well preserved against decay. It is from 50 to 100 per cent more expensive than treated felt.

On some construction work raw burlap has been used (that is, burlap not treated), but such practice is open to the following objections: The hot bituminous binder applied to it in the field cannot properly saturate it, neither is the workmanship in the field always conducive towards such accomplishment, if that were at all

possible. And without proper treatment, the jute fabric will be comparatively short-lived, especially if exposed in the earth with insufficient binder; but this is equally true of the felts and cotton fabric.

The use of treated cotton drill is undoubtedly very good for membrane waterproofing, especially if it is strong and well-treated. In fact, its use is only prohibitive on account of its relatively high cost when compared with either treated felt or jute fabric, especially in view of the fact that the latter is not less efficient in any regard. All are vegetable products and therefore require equally thorough saturation. The cost of the cotton drill, which is at least double that of jute fabric and quadruple that of treated felt, also because a more or less laminated sheet rather than a reinforced unit membrane is formed, especially with the ordinary variety of close-woven cotton fabric, suggests that it be given preference only after careful economic consideration. Saturated cotton drill has been used quite extensively on the Boston subways, and, except for some few leaks that have developed, has given reasonable satisfaction. The very best and most efficient type of membrane is one composed of treated fabric, with small (in size and number) open mesh, united with a uniformly thick bituminous binder. However, for ordinary purposes and for rigid structures, felt is entirely serviceable.

Storing and Unrolling Felt and Fabric. All waterproofing materials are injured by improper storage and usage, particularly the felts and fabrics. Fabric and felt are delivered on the work in rolls usually wound on wooden cores (for types of cores see Fig. 82), from 100 to 150 yards in length and in varying widths from 32 to 50 inches, the 42-inch fabric and 36-inch felt being most common. The rolls should be stored in a dry place, and in warm weather the fabric rolls must not be stood on ends. The most satisfactory way is to pile the rolls not more than 2 or 3 feet high, so as to insure uniform bearing along their length, and never to pile them criss-cross. As it is possible to wind felt much tighter than fabric rolls, they may be stored lying down or standing up. In all cases, both materials should be protected from the weather and from heat at all times.

Due to improper storing, fabric rolls become distorted and otherwise injured, and are therefore often difficult to unwind, resulting in tearing the fabric. Distortion is a defect which tends to create "waves," which persist when the roll is unwound and tend to occlude air in the membrane. Torn or badly wrinkled fabric should not be used. The surface on which the felt or fabric is unrolled preparatory to its use in the membrane should be clean.

Precautions When Heating Coal-tar Pitch and Asphalt. Where coal-tar pitch is used as the binder for membrane waterproofing, it should be heated gradually up to the proper consistency for application. This is usually at a temperature between 250 and 350 deg. Fahr. (121 and 149 deg. Cent.) for a coal-tar pitch with a melting-point between 115 and 125 deg. Fahr. (46 and 51.6 deg. Cent.). Where asphalt is used, it too should be heated gradually, but its working temperature is higher, hence it may be heated to a temperature between 300 and 350 deg. Fahr. (149 and 177 deg. Cent.). Having reached the proper temperatures, the fire should be banked. Heating a 50-gallon kettle full of coal-tar pitch or asphalt to the required temperature for application, by means of a wood fire, should take not less than three to four hours, for the pitch, while in the case of asphalt heat may be applied more rapidly, but should take not less than two to three hours. A more violent heating in either case destroys these materials, especially the coal-tar pitch.

The danger of overheating, burning or coking (particularly the pitch) is constantly present, and cannot be too strongly guarded against. One way to prevent overheating is to stir the pitch occasionally during the melting process, and frequently after it has melted until it is all used. Overheating is preceded by the rising of excessive fumes of a light bluish tinge. Burning is indicated by the rising of yellow fumes from the surface of the pitch. The odor or cackling sound is not an indication of the condition of the bitumen. Neither is the practice of sticking a piece of wood into the molten bitumen a real indication of its degree of heat or of its condition. Coking the pitch is indicated by the formation of a more or less thin crust or coating on the bottom and sides of the melting kettle.

When by accident or otherwise the pitch is slightly burned, new pitch should be mixed with it before using, and, if badly burned, the pitch should not be used at all. It is very essential to the " life " of the pitch not to subject it to prolonged heating, even at a low temperature, as this drives off some of the volatile oils which are a valuable constituent of the pitch. The best practice is to heat only sufficient material for one day's use.

Asphalt, though not as readily affected by heat as coal-tar pitch, also requires in its use the observance of the above rules. The burnt condition becomes manifest by the rise of blue fumes from the surface of the asphalt, and when this happens, the fire should immediately be extinguished, and additional asphalt put into the kettle. If the heat has been excessive and protracted, and if the blue fumes have been excessive and constant for more than an hour, the asphalt

should not be used, because it will undoubtedly have changed or lost some of its properties. The effects of prolonged heating are inversely proportional to the natural hardness of the bitumen.

Precautions should always be taken against fire in the heating kettles, and if one starts water must not be used to extinguish it. As the temperature of the pitch or asphalt during use is far above the boiling-point of water, the result of throwing on water may be serious. Fires may best be put out by the use of sand or steam. As pitch and asphalt hold heat for a considerable time, the workmen should be warned of the danger of being burned by these materials.

Whenever it becomes necessary to transport bitumen, as when the particular waterproofing job is beyond a 500-foot radius from the location of the heating kettles (which is quite common on large construction work), small portable kettles are used for transporting the pitch or asphalt. The same precautions must be taken to avoid burning and coking the bitumen in these kettles as was previously explained for the stationary heating kettles. Where the bitumen is carried in buckets, it is best not to allow these to stand more than a few minutes before using, as the temperature falls rapidly and the material thickens. This condition prevents uniform spreading when the bitumen is mopped on the felt or fabric in making the membrane.

Proper Use of Kettles and Fuel when Heating Pitch or Asphalt. Coal-tar pitch and asphalt have no serviceable affinity in waterproofing by the membrane or sheet-mastic systems. Their mixture produces a product which resembles putty in some of its physical properties, except when the amount present of one or the other does not exceed 5 per cent. Hence the heating kettles should not be alternated; i.e., kettles used for melting pitch should not be used for melting asphalt or making mastic, and vice versa. Where kettles must so be used, it is necessary to clean them, especially where either material has caked on the sides and bottom of the kettles, as often happens. In fact it is good practice to thoroughly clean the heating and mastic-mixing kettles, portable kettles and pails not less than once a week even though their use was intermittent. Kettles encrusted with bitumen or mastic require more fuel and time for heating the contents. The life of the kettle is also reduced by the presence of caked bitumen or mastic.

The easiest obtainable and cheapest fuel for heating kettles is discarded construction timber. Staves of asphalt or pitch barrels are objectionable on account of the unbearable volumes of smoke they produce. Much trouble and a public nuisance would be avoided

if there was a law prohibiting their use in city streets. Cord wood is the best to use, because with it a smouldering fire may be maintained for a long time. This keeps the bituminous material hot without burning it.

Differentiating between Coal-tar Pitch and Asphalt in the Field. Engineers unfamiliar with bitumen find it difficult to distinguish between coal-tar pitch and asphalt, consequently, mistakes sometimes occur by using one for the other. Asphalt may be a product of asphaltic petroleum, a refined natural asphalt or a mixture of both. Coal-tar pitch is a product of the destructive distillation of coal in the manufacture of coke or illuminating gas. The following characteristics will aid in identifying each on the work. Asphalt, when newly cut, is a bright, lustrous black. It has a pungent and somewhat rancid odor and taste. With the application of heat of equal intensity, it requires longer heating than coal-tar pitch to be brought to the same liquid condition or equal temperature. When asphalt burns without flame its fumes are decidedly blue. Coal-tar pitch, when newly cut, is somewhat of a dull black and more brittle, as compared to asphalt. It has an aromatic taste and odor, which is characteristic of pitch only. When coal-tar pitch burns without flame, its fumes are a dense, greenish yellow. The safest and most advisable thing to do where both materials are used on the same work is to require the manufacturers to mark or label the containers, so as to make identification easy and certain.

Coal-tar Pitch Versus Asphalt for Waterproofing. Whether asphalt or coal-tar pitch is to be preferred for membrane waterproofing is still a mooted question. No doubt, for certain special uses, as for instance, where the temperature varies widely, the asphalt is a preferable material because it remains soft and workable through wide temperature ranges; if the temperature varies but little, as it often does in underground work, straight-run coal-tar pitch will give better results on account of its greater chemical stability. But on general construction work, a good quality of either material is equally serviceable, the prevalent contrary view among engineers notwithstanding. The author's experience has led him to the conclusion that certain brands of asphalt now on the market are even to be preferred to some grades of pitch, for this reason: The asphalts (all too few, though) as now refined, have been constantly improving in quality, while coal-tar pitch did not keep pace. In fact, in the last decade or so, on account of the increasing value and importance of the by-products from coal tar, and, due to the keen competition in the waterproofing field, the

quality of pitch has materially suffered. Where the quality of pitch or asphalt can be controlled or ascertained and verified, however, their preference for waterproofing purposes, assuming the consistency to be right for the climate or local requirement, becomes a question of cost. The heretofore superiority of pitch was due to the fact that asphalt was often produced as a by-product in oil refineries. Now the practice is being reversed, hence the improved quality of asphalt now available. But of course, good straight-run coal-tar pitch is also available. The point to remember is that both materials, if of good and certified quality, are practically equally serviceable, with the exception noted above with regard to adaptability.

Mastic System of Waterproofing

Definition, Purpose and Development. The mastic system of waterproofing consists of (1) the application of sheet mastic (composed of asphalt or coal-tar pitch, sand, grit and cement or stone dust), in the form of a comparatively thin layer, which more or less surrounds the structure to be waterproofed; (2) a brick-in-mastic or tile-in-mastic layer composed of a course or two of bricks or tile, the joints being filled and all faces covered with a bituminous mastic, the course or courses covering the structure below ground-water level.

The sheet mastic varies between $\frac{1}{2}$ inch and 2 inches in thickness; the brick-in-mastic varies between $2\frac{1}{2}$ inches and 8 inches in thickness. The brick-in-mastic layer, being between five and eight times as thick as a 3- or 6-ply membrane, and from four to five times as thick as the sheet mastic, is usually used where great water pressure exists. It is the most dependable system of waterproofing, though also the most expensive. In underground construction where headroom is a factor, or in general where insufficient space exists for the application of one or two courses of brick-in-mastic, and where sheet mastic cannot be used, as for instance, on sidewalls of subsurface structures a fabric membrane of from 4 to 8 plies is usually substituted. A felt membrane of an equal number of plies should be used only when reinforced with 1 ply of fabric for at least each 3 plies of felt. This precaution is not necessary, however, on very rigid structures, or where expansion joints properly distributed in the structure, are provided.

Almost simultaneously with the development of the fabric membrane went the development of the sheet mastic and the brick-in-mastic layers. Originally, a coating of mastic (composed of rock

asphalt, fluxed to the proper consistency) between ½ and 1½ inches thick, was used mainly on horizontal surfaces.* In an effort to increase the depth and weight of this coating for waterproofing purposes, both on horizontal and against vertical surfaces, bricks or tiles were introduced between thinner layers of mastic. Finally, even the brick joints were filled with mastic, resulting in the present day brick-in-mastic layer or envelope. Where this scheme is used for waterproofing, the materials are always incased between concrete or other masonry surfaces.

Applying Mastic Waterproofing. Sheet mastic for waterproofing is mostly used on railroad bridges though it has been employed on underground construction. It is most extensively used as a waterproof floor for buildings and railroad stations. Sheet mastic is, however, subject to abuse in its manufacture and application. For instance, the quantities of the various mineral ingredients might be poorly proportioned, resulting in a mastic that is too soft or too hard; the quantity of bitumen might be insufficient to give good cohesiveness and elasticity to the mastic. The sheet mastic might be applied without sufficient precautions to prevent cracks produced by movement due to temperature changes especially over large areas. While the particular purpose in hand should always be considered in proportioning of the ingredients for making sheet mastic, still the following general directions should be adhered to: the bitumen and the sand should each be not less than 10 per cent of the finished mastic; the fine mineral dust, whether limestone dust or cement, should be not less than 45 per cent, and the grit not more than 30 per cent of the finished mastic; the remaining 5 per cent is sufficient, if carefully apportioned, to take care of any special requirements of the mastic.

When serving only as a waterproofing medium, sheet mastic must be continuous over the surface to which it is applied, but its abutting extremities must not be relied on to make a watertight connection with steel or concrete without special provision being made to obtain such a condition. This may be accomplished by a cove finish of the ends or by the use of an adhesive, plastic joint filler. Often sheet mastic is used in conjunction with other systems of waterproofing as, for example, to cover a felt or fabric membrane. With due precautions in its application, sheet mastic constitutes a good

* The use of sheet mastic (or sheet asphalt as it is popularly called) dates back to 1838, when it was used to make sidewalks in Paris. It was made of a bituminous limestone from Seyssel and Valde Travers, and since then nearly all European asphalt paving has been done with this asphaltic limestone.

waterproofing medium, comparable to the brick-in-mastic system. Sheet mastic can be made to withstand shock and vibration without cracking by introducing a wire mesh or cloth reinforcement between equal thicknesses of mastic forming the layer. It is much cheaper than brick-in-mastic, but is not as generally applicable.

Compared to felt or fabric membranes, the use of brick-in-mastic to waterproof a structure is more costly, and its application often more difficult and more exacting. The reason for this is that the amount of labor necessary for preparing the mastic and laying the courses to form the envelope about the structure is considerably more, as also the quantity of material required for equal areas to be covered, than the bituminous membrane. Figs. 19 and 20 illustrate some of the difficulties contended with in the application of brick-in-mastic to an underground structure, such as a subway. The section in Fig. 18, representative of the construction of the new Dual Subway in New York City, shows a typical arrangement of the waterproofing used on this work. The brick-in-mastic, by its substantial nature, protects the floor from percolation due to pressure, and the bituminous membrane protects the roof from seepage of ground water.

The condition of a structure to be waterproofed is not always what it should be to receive the envelope of brick-in-mastic, hence the structure must be made adaptable by artificial means such as smoothing, drying, cleaning, etc. It may not be feasible to wait until the concrete dries before applying the brick-in-mastic, or the weather may make it difficult to obtain a dry surface. Where a wet or damp surface is unavoidable, a ply of felt or fabric or a membrane consisting of the two combined should be placed thereon and its surface mopped with asphalt if asphalt mastic is being used, or with coal-tar pitch is pitch mastic is used. Pools of water and a decidedly wet concrete should first be made reasonably dry by suitable means before this dry ply is laid. But no dependence for waterproofing is to be placed on any form of dry ply.

The waterproofing mastic is usually brought to the place of application in portable fire kettles or small pouring pails. The mastic should not be allowed to stand in these for more than a few minutes before using. Failure to observe this results in a loss of heat and uniformity of mixture due to the quick settling of the mineral aggregate. In any case the mastic should be well stirred before pouring it on the prepared surface. The carrying pails must be scraped after each pouring to avoid caking of the mastic on the bottom by continued settlement. The mastic should always be

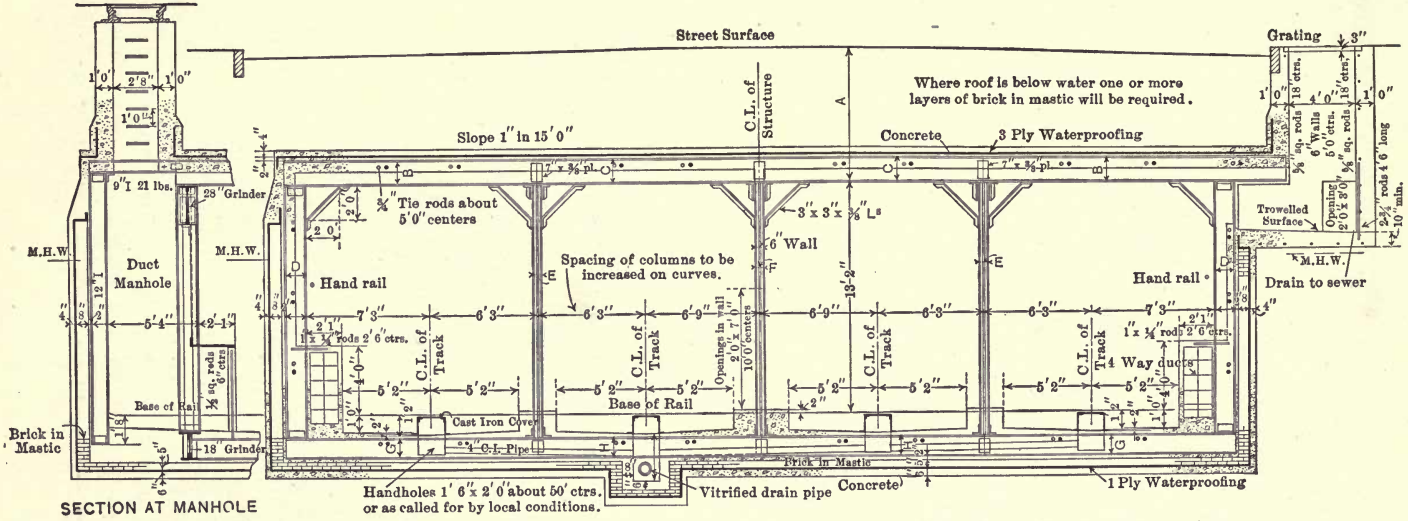


FIG. 18.—Typical Cross-section of Four-track Subway. (Steel Bents Placed on Five-ft. Centers.)

spread out to a uniform and reasonably thick film (about ½ inch) before laying the bricks therein.

The bricks, whose function is to give a substantial and thick waterproofing layer, are laid in the mastic so as to be completely surrounded by a film not less than ⅛-inch thick. In no case should brick touch brick. A simple method of obtaining good and completely filled joints around the bricks is to slide each brick into place, somewhat diagonally and with a slight pressure downward. This will invariably bring the bed mastic up into the joints. Spalls should not be used under any circumstances. An effort should be made to use whole bricks, and bats but sparingly. In applying more than one course of brick-in-mastic it is best to build each almost simultaneously, with the lower course not more than a few feet in advance of the upper. Where two courses are decided on (in which the bricks are ordinarily placed on their largest bed) it will often be found profitable without materially reducing the efficiency of the envelope to build a one-course envelope, but with the bricks laid on the narrow side. This scheme will effect a saving of 22 per cent in material alone.

Each course of bricks is to be covered with mastic so that all joints and hollows are filled, making the surface even. When spreading the top coat of mastic, care is to be exercised in joining successive pourings. This top coat sometimes becomes pitted or perforated with numerous pinholes exposing the bricks. This may be largely overcome by increasing the amount of the fine mineral aggregate or by adding a small amount of asbestos fiber. When such a perforated condition is detected in the finished envelope it should be resurfaced with the pure bitumen.

Laying protective concrete should proceed immediately or shortly after the surface mastic has cooled. The top or exposed film of mastic covering the bricks must be cleaned in a manner similar to that previously described for membranes. Where temporary construction timber cannot be removed during waterproofing operations, these locations must be taken care of similarly as described under the "Membrane system." The forms placed about post holes to prevent the protective concrete from flowing into the same, should be made watertight to avoid coating the asphalted bricks as it is difficult to remove the set mortar afterwards. In pouring the protective concrete on the mastic, it is safest not to exceed a drop of 6 feet in height to avoid injuring the top coating. The surface of the protective concrete should be troweled smooth.

Precautions when Joining New and Old Brick-in-Mastic. The ends of the courses at the finish of each day's work, or when work is temporarily discontinued, must be well mopped with asphalt or coal-tar pitch, depending on the kind of mastic used, leaving no bricks uncoated. To preserve the physical condition of these ends, 2-inch boards may be laid up against them, especially where resumption of work may be delayed for a long time. In commencing the new work, the old surface should be cleaned and softened so as to properly join with the new mastic. The use of a gasoline torch or the burning of some gasoline on the surface is sufficient to accomplish this.

Where temporary braces, posts and other supports are used on the work and are not moved to accommodate the brick-in-mastic layers, all four sides of such post holes should be stepped when more than one course is used (see Fig. 16). In waterproofing these post holes after removing the posts, all surfaces are to be carefully cleaned and remopped with bitumen. The mastic is then poured on the prepared area and the bricks embedded therein in the ordinary way. It is advisable to dip these bricks in bitumen or mastic before laying. In fact, all possible precautions should be taken to secure an absolutely watertight joint on all kinds of patch work.

Placing Mastic around Projections and in Vicinity of Steam Pipes. If, through a masonry surface which is to be waterproofed by the application of a layer of sheet mastic or brick-in-mastic, such objects as pipes or rods project, careful workmanship is required to make these locations watertight. Whatever the object be, that part of its surface which will be included in the waterproofing layer must be cleaned thoroughly. If these objects project through a floor or roof, then it is well to leave an open ring about 2 inches wide, completely around them, as the course or two of brick-in-mastic is laid down. Then this ring space is preferably filled with a mastic of softer consistency than that used ordinarily, or with pure asphalt. Sheet mastic may be applied without this temporary space around projecting objects. If objects project from vertical surfaces, it is first of all necessary to make the form (required for placing brick-in-mastic against walls) fit snugly around the object. Then the bricks should be so laid in the mastic at these projections as to leave a space about 1 inch wide around them, to be filled by the mastic. A better bond will be secured between the mastic and the pipe, rod, or other projecting objects, if these are first swabbed with pure bitumen. In some instances, where the importance of the work warrants it, the efficiency of these connections will be enhanced

by the judicious application of waterproofing felt or fabric, as for instance, if the joints were made as described under " the membrane system"; then, by the further filling of the ring spaces with mastic or pure bitumen, more positive joints are secured.

In the event that steam or hot-water pipes or mains project through the masonry, then it is first necessary to insulate them so as to reduce the effect of their radiating heat to a minimum. The usual method for doing this is also described under " the membrane system."

Preparation of Wall Surfaces for Brick-in-Mastic. When exterior waterproofing is intended for an underground structure running through rock, an effort is made while excavating to leave the natural sides as vertical and smooth as possible. But this is never attained. Hence a sand wall of concrete is applied against the natural rock to supply a vertical and smooth surface. This acts as the " armor-coat " for either the membranous or mastic type of waterproofing. Excavation in earth requires the customary sheet piling and bracing. This sheet piling is generally placed sufficiently outside the neat line to permit the building of either a one-course brick or terra-cotta hollow-tile wall. This wall then acts as an " armor-coat " for the waterproofing. In some instances steel or wooden sheet piling is so placed as to preclude the possibility of building a masonry wall within its confines, then this piling is made to act as the armor-coat for receiving the waterproofing. (Fig. 19.) These conditions, however, only occur on large and difficult work where they must be given special consideration.

If the masonry armor-coat against the rock surface or sheet piling is too wet to receive the waterproofing, or when the sheet-piling armor is in a similar condition, then a so-called dry ply of either felt or fabric, or a combination of the two, is first applied. Where water is actually running over the face of the wall or sheet piling, it should be diverted temporarily. This may be done either by inserting sufficient bleeders at the best elevation, or by attaching a strip of tin in the shape of a trough above the space to be waterproofed. Plaster of Paris or cement may be used for attaching this strip. If, by these methods, the surface cannot be made thoroughly dry, a dry-ply of felt and fabric combined is to be hung up against the surface. The brick-in-mastic is then laid against it in such a manner as to permit the water to flow down and progressively forward and out from behind this dry ply. Wherever there is no direct water to contend against, as above noted, the dry ply may consist of strips of felt or fabric, mopped in the usual way. In building the armor-

coat of concrete, the form for it should be made rigid so as to avoid bulging. Neglect of this precaution causes a reduction in the cross-section of the brick-in-mastic wall, a condition to be avoided, as eventually it may be the cause of leaks, due to the careless practice

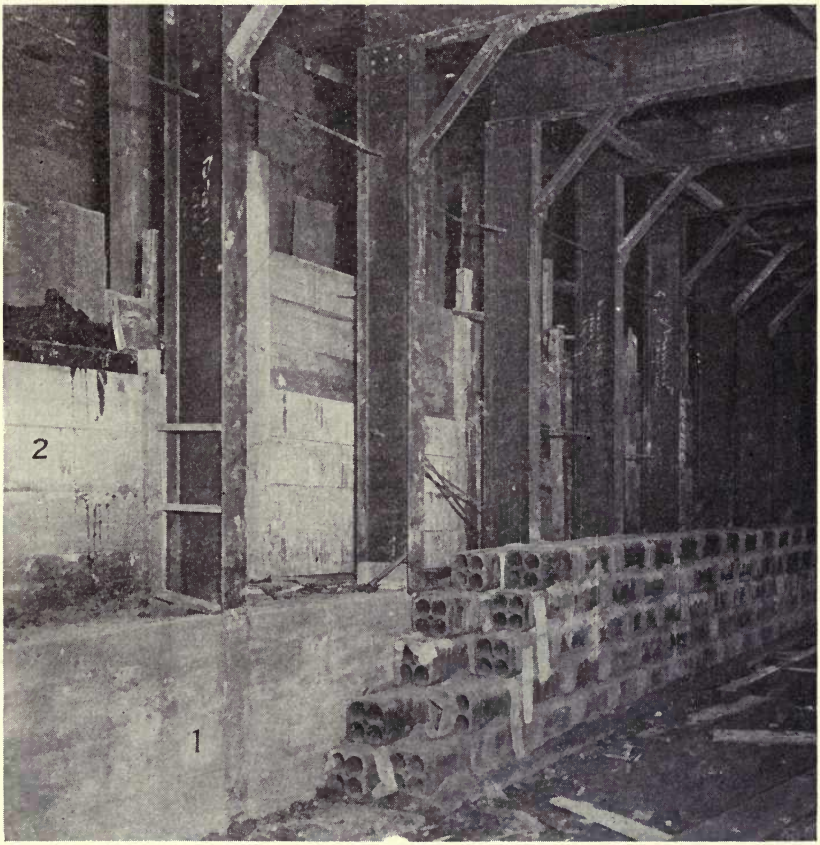


FIG. 19.—Showing Partly built Main Wall, 1, and Forms for Brick and Mastic, 2. Note Top Row of Bricks Covered with Mastic, and Sheet Piling left in Place Acting as Armor for Waterproofing.

of filling the narrow parts of the forms with small pieces of brick, or squeezing in whole bricks and thus thinning the joints.

Precautions for Setting-up, Filling and Stripping Forms for Brick-in-Mastic Walls. In building brick-in-mastic walls, forms are necessary mainly to allow the mastic to set, and in warm weather, even after. Fig. 19 shows a form for a two-course mastic wall in

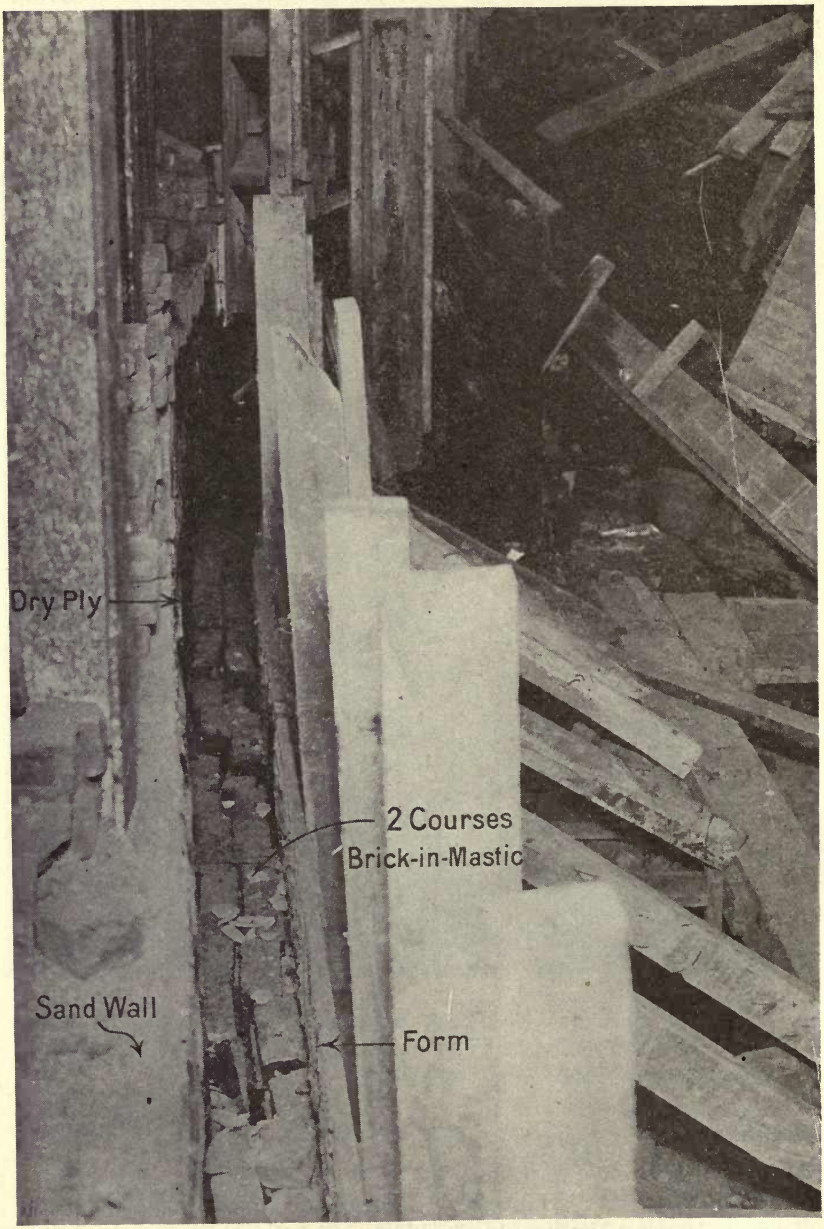


FIG. 20.—Building of Two-course Brick-in-mastic Wall, Showing Form, Form Bracing, and Sand Wall.

course of construction against a sand wall preparatory to the placing of the finished wall within. Therefore, after the surface of the armor-coat has been properly prepared, the forms should be placed the required distance from it. This distance is governed by the manner of laying up the bricks; i.e., if the longest edges of the bricks are perpendicular to the wall (all bricks being laid as headers) $8\frac{1}{2}$ inches form space is required; if they are laid parallel to the wall in two courses, 8 inches are required, and in single courses, 4 inches. Of course this assumes the use of common red brick, as no better or special kind is necessary. The height of form sections are not to exceed 3 feet, so as to enable the waterproofer to easily reach the bottom in laying the bricks. In bulkheading the forms, tight joints are necessary.

To insure the easy and successful stripping of forms, the inner surfaces of the forms are to receive a wash coat of neat cement, or have a strip of felt attached. Washes of lime or clay may also be used to good advantage, but in no case should lumpy clay be applied. Any of these coatings are best applied before the forms are set up.

When the forms are erected, a pail of mastic is poured and spread uniformly therein. The bricks are immediately embedded in the mastic, usually on their largest bed and with their longest edge parallel to the wall. In laying the brick no mastic should be allowed to collect or extend beyond any course of bricks. In laying the successive courses of brick, they may be made to break joints in the same manner as in a brick and mortar wall, but this is not essential. Where the space between the wall and the form is not wide enough to allow one or two bricks as the case may be to be laid on their largest bed and with proper joints (in the manner described above) due to bulging of the sand wall or armor-coat, the bricks should be laid so as to leave more mastic in the joints and faces. Sometimes a ply of fabric is added for each inch of reduction of form width due to this bulging, but this is inadequate and should be guarded against.

Settlement and Bracing of Brick-in-Mastic Walls. Where the mastic forms must be removed prior to the building of the main wall, the mastic wall should be well braced to prevent buckling and undue settling. In warm weather the removal of mastic forms should be done only shortly before building the main wall. Where failure to observe this rule has caused any decided deformation in the mastic wall, this portion should be cut out and properly replaced with new materials. But quite often it will be possible to push the bulge back

into place by applying a constant force, pressing on as large an area of the bulge as possible.

All asphalt mastic on cooling will reduce in volume and settle, (about $\frac{1}{8}$ inch in a height of 10 feet per 30 deg. Fahr. (16.5 deg. Cent.) change in temperature for a 2 : 1 : 1 mastic) therefore no concrete should be placed on top of a mastic wall until complete cooling and settlement has taken place in it. Neither should a mastic wall be counted on to carry any weight at any time because it cannot perform this function by the very nature of its make-up. On extended flat surfaces, however, it can be made to safely carry about 300 pounds per square inch at about 60 deg. Fahr. (15.5 deg. Cent.) if movement in the layers is impossible.

Where a mastic wall is to join the brick-in-mastic on the roof of a structure, it should be brought up to the level of the roof-masonry, and allowed to settle and cool, then the mastic on the roof should be laid and joined to the wall mastic. The protective concrete or other masonry is then laid so that its joints are not directly over the joints in the mastic waterproofing.

Materials for Making Mastic: their Properties and Proportions. Asphalt or coal-tar pitch may be used for making mastic. Both must be carefully selected and tested to insure their adaptability. The usual practice is to use a minimum of 33 per cent of bitumen, but this may be decreased to 25 per cent where a stiff mastic is required, or increased to 50 per cent where a less viscous mastic is desired. The mineral aggregate, the presence of which tends to increase the tensile strength of the binder, is usually sand, cement or limestone dust, and sometimes asbestos fiber is added as a filler. The proportions are often arbitrarily and carelessly specified. The aim in this regard should be to proportion the mineral filler to produce maximum density which insures maximum strength.

The sand for making mastic should all pass through a 10-mesh sieve. It should never be used when wet or moist, and in general, should be heated before using. (Figs. 77 and 78 show the customary ways of doing this.) This will lessen the formation of bubbles and pin holes in the mastic caused by the escape of the occluded moisture. The sand should also be clean, free from dirt, silt, or vegetable matter.

Any cement in good condition is suitable for making waterproofing mastic. Fineness of the material is the important factor, because the finer the grain, the more intimate is its incorporation with the bitumen. The limestone dust need not be as fine as the cement, but it should pass at least 80 per cent through a 100-mesh

sieve, and 10 per cent through a 200-mesh sieve. Slate dust is sometimes substituted, but it usually lacks the fineness of either cement or limestone dust.

Bricks used for brick-in-mastic waterproofing should be of good quality common brick, burned hard entirely through, regular and uniform in shape and size and of compact texture. They should also be heated to complete dryness before using, and so heated as to remain practically clean, i.e., free of excessive soot. The various methods for doing this are discussed below.

The two-thirds mineral aggregate referred to above may consist of a mixture of sand and cement or sand and limestone dust with a reasonable amount (not more than 1.5 per cent), in either case, of asbestos fiber. The latter material, however, may be dispensed with, as it is only necessary in special cases, as, for instance, on the top or final coating of the mastic layer when this is located a few feet below ground surface. The sand and cement is usually mixed in equal proportions by weight or volume, but it would be much better to mix these with due regard to the percentage of voids in the sand. In the rare instances where mastic is to be laid in a very wet location, more mineral matter should be used, as this will increase the weight of the mastic and decrease the tendency to create bubbles in the asphalt due to the steaming and upward pressure of the water, also when it is to be used on an incline, as more sand stiffens the mastic. In the mastic that is used as a top coating for the upper course of bricks, less sand should be used. This will leave the mastic more ductile and plastic, permitting it, if cracked, to heal more readily when the temperature is suitable An addition of asbestos fiber may be made instead of reducing the sand, as this also gives a more flexible coating.

Hand- versus Machine-made Mastic. When making waterproofing mastic by hand, it is important to see that the sand and limestone dust are thoroughly dry. The sand and cement or limestone dust are first mixed in proper proportions and then put into the mixing kettle after sufficient asphalt has been melted therein. The temperature of the asphalt mastic should be kept between 350 and 400 deg. Fahr. (177 and 204 deg. Cent.) and coal-tar pitch mastic between 275 and 325 deg. Fahr. (135 and 163 deg. Cent.). The aggregate should not be dumped into the melted asphalt but sprinkled into it. Stirring the mastic must be continued until a uniform mixture has been obtained. This requires at least twenty minutes of continued stirring for a 50-gallon kettle.

On large work a battery of mixing kettles is usually centrally

located, but where the particular waterproofing jobs are beyond a 500-foot radius from the mixing kettles, the mastic must be transported in portable fire kettles. The mastic in the mixing kettles is to be stirred before pouring into the portable kettles, and when it arrives at the place of waterproofing, the mastic should again be stirred before pouring into the carrying pails. No mastic from the hot portable kettles must be poured into the carrying pails unless it is to be used immediately, otherwise settlement of the aggregate results and the uniformity of the mixture is destroyed.

The practice of making mastic by hand in open fire-heated kettles is as old as the mastic industry, which began between 1880 and 1885. But, though paving mastic has for many years been made by machine, floor and waterproofing mastic continue to be made by hand. This is partly due to the fact that (1) heretofore such mastic was not a commonly used material, (2) natural rock asphalt was mostly used in the belief that an artificial mastic was impossible or very inferior, (3) the secretiveness with which the mastic industry was developed,* and (4) the comparatively small quantities of floor mastic generally called for on any particular job.

Making reasonably good mastic by hand is of course possible. But there are many drawbacks not usually considered. For instance; the consistency of the mastic is usually determined by the operator and hence no two batches are alike; neither are the proportions of ingredients constant, for they are usually dumped in by "eye"; then, what is worst of all, the man mixing the mastic naturally desires to lighten his labor and occasionally either does not sufficiently mix the batch, or adds more bitumen than the amount specified. All of these objections would be absent in a machine-made mastic, because the ingredients would necessarily have to be weighed or measured, as is done in mixing concrete by machine. The quality would also be easily regulated and the engineer could better inspect the work to see that his specifications were lived-up to, especially in the matter of cooking the mastic. On large work this is very important.

A type of mastic-mixing machine which makes this possible, and indeed, makes a superior mastic, is shown in Fig. 67. The author, who has experimented with and observed the product of a machine of this type for a long time, can state confidently that it would be to the interest of the mastic industry to abolish the hand-mixed product and resort to a machine-mixed mastic, especially

* In the early days of the mastic industry it was not beneath some of those engaged in it to employ the tricks of witchcraft to fool the inquisitive.

because of its economy. This economy results from the fact that the asphalt does not have to be first melted and heated as with the use of open kettles, and also because none of the mineral aggregates needs preheating. This is all accomplished in the drum of the machine, which, besides, can mix a much larger batch in considerably less time than men can mix it in open kettles. Machine-mixed mastic is, however, admittedly impracticable on small jobs, and has not yet been used for making waterproofing mastic such as described above, that is, its use heretofore has been limited to floor and paving mastic.

Brick-heating Methods. In the use of bricks for brick-in-mastic, the question often arises as to (*a*) when the bricks should be heated, (*b*) to what extent they should be heated, and (*c*) by what method they should be heated. In answering these questions experience is the best guide. Bricks used as above noted should be heated (*a*) when the temperature is below 40 deg. Fahr. (4.5 deg Cent.), (*b*) when they are moist or damp (because either condition prevents good bonding between the bricks and the mastic), (*c*) they should be heated to a degree not exceeding that which permits their being handled with the bare hands (because otherwise the mastic film surrounding the bricks will be melted off), and (*d*) the method of heating should be such as will not cover the bricks with an over amount of soot, because this tends to prevent proper bonding, and bonding is very essential to the continuity of the layer or envelope of brick-in-mastic.

A method of heating bricks to be strictly avoided is the following: A small make-shift furnace, constructed by enclosing three sides of a convenient area with walls of either brick or stone, laid dry. These walls are of any convenient length and about a foot high; the fourth side remains open and through it the fire is fed. On top of the walls is placed a wire screen strong enough to support about 200 or 300 bricks piled promiscuously. A wood fire is kindled underneath and the heat and smoke pass up between the bricks. This method not only fails to heat the bricks alike but also covers them with more or less soot, and is slow and wasteful.

A better method is the following: A hollow cylinder about 4 or 5 feet in diameter is made by piling bricks one upon the other with loose joints, but interlocked so as to make the entire cylinder self-supporting. The bricks are laid on their largest bed and built up to a convenient height, say 3 or 4 feet. Next, a wood fire is made within the cylinder, or, better still, a coke fire is maintained in a salamander placed within the cylinder. If a wood

fire is used the flames should be kept low. This scheme permits the escape of smoke without covering the bricks with soot. The radiating heat dries the bricks to any desired degree depending on how long they remain near the fire. If a second row of bricks is built around the first one it will receive its incipient heat and as the inner cylinder of bricks is used up the outer one will gradually receive its share of heat. This method, however, is also slow. A mechanical brick heater is described in Chapter VI, and is the most efficient means for heating and drying bricks known to the author.

Weather Conditions Governing Waterproofing Operations. To obtain the best results, no waterproofing should be done wherein ordinary bitumen is used as the cementing or binding material, especially in the form of a membrane, sheet mastic, or brick-in-mastic layers, when the air temperature is below 40 deg. Fahr. (4.5 deg. Cent.), nor during snow, rain, or drizzle. Coal-tar pitch chills rapidly in cold weather and will not stick well to cold masonry; and asphalt is even less adhesive to cold masonry. Neither pitch nor asphalt will adhere to a wet surface, therefore these conditions must be avoided. However, if the work be amply protected from cold and wet weather, waterproofing may proceed with due precautions for eliminating the hazards of these conditions. On the other hand, in warm weather, care must be taken to protect the finished waterproofing promptly, especially if it is exposed to the sun, otherwise expensive repairs may become necessary, before or soon after completion of the work.

Integral System of Waterproofing

Definition, Purpose and Development. The integral system of waterproofing is the process of making impermeable mortar or concrete by incorporating in the mass, certain ingredients which act either as void fillers, as lubricants for the aggregate, or chemically upon the cement, thus densifying the mass. These ingredients consist of (1) finely ground powders, such as clays, silicates, feldspars and hydrated lime, which are usually mixed with the dry cement at the mill or on the work; (2) liquids and pastes such as stearate of lime (water-insoluble soap), sodium or potassium oleate (water-soluble soap), aluminum stearate, calcium chloride and oil compounds, which are usually mixed with the gaging water, though they are sometimes added to the mixed mass to form an integral part of the resulting mortar or concrete.

The fillers may be inert or active. If inert, as the above powders

are, they merely fill up the pores or voids inherent in the concrete, but if active, as the above soap compounds are, they may either unite with the cement or crystallize in themselves. The resulting compounds tend either to fill the voids and barricade the pores or to become water repellent. Most of the liquids and some of the powders are inactive lubricants of a fatty nature, and these assist the aggregates to slide more compactly into place.

The purpose of the integral system of waterproofing is to make concrete and mortar impermeable by the application of the waterproofing materials during the process of mixing, thus reducing the cost of the construction by eliminating the necessity for any additional treatment. This system of waterproofing, however, does not remove the need for thorough mixing and careful placing of the concrete.

The integral system of waterproofing is best adapted for treatment of structures in the course of construction, principally of the type not subject to vibration or shock. For water tanks, dams, foundations, and other stationary or rigid concrete structures, where absorption or percolation through the concrete may work serious havoc, it is particularly well adapted. However, the possibilities of making mass concrete impermeable by the simple expedient of carefully grading and correctly proportioning the aggregate and prolonging the time of mixing should not be forgotten. For railroad subways and bridge floors, this system should not be specified, no matter how promising may be the materials offered; for, even if the waterproofing materials added do not weaken the concrete (as sometimes happens when inferior compounds are used), they cannot prevent its cracking under vibration of traffic and the consequent percolation of water through such cracks.

The incorporation of foreign ingredients in mass concrete to increase its density, or, what amounts to the same thing, decrease its permeability, is not so very old. Originally quick lime was used, then certain patented compounds began to appear on the market, such as stearates and resinates (water-insoluble substances), and finally hydrated lime began to be used for this purpose. In recent times numerous secret and patented compounds have been extensively used, but owing to a general dissatisfaction with the results obtained, they have received a considerable setback. And with them some very good materials were thrown into disrepute. The practice of adding an arbitrary but small percentage of cement over and above the calculated amount is quite prevalent, and often accomplishes the results claimed for many of these special compounds.

Limitations of the Integral System of Waterproofing. The use of integral waterproofing compounds should be limited to conditions where certainty exists regarding character of stresses in the structure, and then only after the materials have been analyzed, tested and proven efficient. The following pertinent remarks by the U. S. Bureau of Standards* corrobate the foregoing: "The addition of so-called integral waterproofing compounds will not compensate for lean mixtures nor for poor materials, nor for poor workmanship in the fabrication of the concrete. Since in practice the inert integral compounds (acting simply as a void-filling material) are added in such small quantities they have very little or no effect on the impermeability of the concrete. If the same care be taken in making the concrete impermeable without the addition of waterproofing material, as is ordinarily taken when waterproofing materials are added, an impermeable concrete can be attained."

The incorporation of any kind of integral waterproofing material into a mass of concrete will not materially prevent the formation of hair cracks or temperature cracks or cracking due to uneven settlement. Results with different materials will vary, but very few have proven entirely satisfactory. Neither can this system prevent seepage through day's work planes, and expansion joints, or joints between steel and concrete. Furthermore, this system of waterproofing, or rather the materials used in connection therewith, may reduce the strength of concrete and sometimes may even induce disintegration in the concrete. The integral waterproofing materials that will not do these things are, in fact, few, and their successful use requires so much care and labor that better results may often be obtained by the self-densified system of waterproofing.† In the light of present-day knowledge and experience with integral waterproofing compounds, their use and need are debatable on the basis of real efficiency. There are many cases, nevertheless, where any other system of waterproofing as well as the integral system might be used with equally good results, the selection under such circumstances, being, of course, a comparison of costs. The integral system has, however an advantage always worthy of consideration,

* Technologic Paper No. 3, p. 83.

† The author is able to say that several manufacturers of integral waterproofing materials have admitted this to him, but they asserted that these materials are worth their cost merely by acting as a factor of safety. It seems more probable, however, that these materials act more psychologically than as a safety factor. That is to say, workmen will probably feel more inclined to prolong the mixing and tamp more vigorously when told or shown that something has been added, but which will really be effective only by such activity.

namely, it requires no additional excavation or protective masonry, and the waterproofing operation proceeds with the construction, which is often a great advantage. In justice to some materials of this type that have apparently given satisfaction, it must be admitted that there is really great need for more extensive, and exhaustive practical tests, that is service tests, on this entire class of materials.

Integral Waterproofing Materials and Their Application

The types of materials above mentioned namely, powders, pastes and liquids, will now be considered in a more detailed manner. The many integral compounds appearing on the market are mostly of a water-repellent nature, but their compositions are seldom divulged, except those which are patented. The powders are usually of a white, floury consistency, and water-repellent. This property is imparted to them by the addition of some metallic stearate such as limesoap, which is of a fatty nature. The fineness of the powders gives them their void-filling properties, while those of a fatty nature act also as a lubricant for bringing into closer proximity the constituent materials of the concrete. The addition to the concrete mass of various amounts of hydrated lime also creates a dense mixture by the same process.

Use of Hydrated Lime. In regard to the addition of hydrated lime, experience has demonstrated that it serves to increase the plasticity and also to lubricate, as it were, the aggregate of the concrete, resulting in a denser and more uniform mass. But the United States Bureau of Standards* states that the value of hydrated lime as a waterproofing medium is probably due to its void-filling properties, and that the same results could be expected from any other finely ground inert material, such as sand or clay. While this is true, it is none the less an indisputable fact that hydrated lime acts in a greater measure as a lubricant, which the others would only do in a very limited way. Many proprietary compounds are composed mainly of finely ground sand and clay.

By adding from 10 to 15 per cent of hydrated lime, the tendency of concrete to check and hair crack is materially reduced, as the lime absorbs and retains a large percentage of water and therefore holds the moisture in freshly poured concrete until the slower acting cement can utilize it.

Mr. Sanford E. Thompson,† in a series of experiments on the

* Technologic Paper No. 3.

† American Society for Testing Materials, June, 1908.

effects of hydrated lime in concrete, arrived at the figures in Table IV in regard to the effective proportions of hydrated lime for producing water-tight concrete.

TABLE IV.—PROPORTIONS OF HYDRATED LIME FOR IMPERVIOUS CONCRETE

Portland Cement (Parts).	Sand (Parts).	Stone (Parts).	Hydrated Lime (Per Cent).
1	2	4	8
1	2.5	4.5	12
1	3	5	16

The percentage of lime is in terms of weight of cement. The sand and stone are representative of average materials throughout the country. The coarser the sand, however, the more lime should be used.

Lime paste occupies more than two times the bulk of paste made from an equal weight of Portland cement. Hence, by replacing the cement in mortar by about 15 per cent of hydrated lime, its density, and in consequence its strength and permeability are increased.

But even with the addition of hydrated lime, the concrete materials must be graded, and the proper proportions of cement and hydrated lime used. If the concrete is poorly mixed or made with insufficient water, or improperly placed, or if joints are left unprotected, the structure will inevitably leak. The mixing must be thorough, sufficient water must be employed to give a " mushy " mixture so that it will settle into place with the least amount of ramming. Fully as important as the care in mixing is the bonding of one day's layer of concrete with the next; even small interruptions of an hour on a hot day will materially injure the bond of the concrete.

Use of Inert Fillers. Inert fillers vary greatly in durability and resistive properties, and should therefore be selected with considerable care. A governing property of all inert fillers is that they should not only be inert in the presence of the cement but also to atmospheric moisture and gases and percolating waters.

Many fillers now used consist of clay, sand, lime and ordinary natural or Portland cement, this latter in a form exceedingly finer than ordinarily used, or in the form of " excess quantity " to make a rich mixture of the mass of mortar or concrete.

The chemical composition of some inert powder fillers are given in Table V together with a comparative analysis of average Portland and natural cements. The first two are taken from a Technologic Paper of the United States Bureau of Standards* together with part of the following remarks:

"Those materials which act as void fillers or increase the density of the concrete and are without any action on the cement and do not themselves change, are known as inert fillers. Included in this class

TABLE V.—ANALYSIS OF INERT FILLERS

(Clays, Sand, Feldspar and Hydrated Lime)

	N. Y. Clay.	Mo. Clay.	Feldspar.	Sand.	Hydrated Lime.
Silica	58.30	72.91	64.02	89.50	1.34
Alumina	16.85	15.01	19.38	2.36	.45
Ferric oxide	6.41	2.79	.70	2.58	.13
Manganese oxide	.06	.03	trace	.12	.....
Lime	4.22	.59	.87	1.37	46.90
Magnesia	2.92	.85	.33	.57	32.19
Sulphuric anhydride (SO_3)	.12	.12	.10	.21	4.02*
Sodium oxide	.77	.80	2.52	.26	.....
Potassium oxide	2.71	2.12	11.76	.70	15.05†
Water (105°)	.60	1.12	.06	.20	.....
Ignition loss	7.00	3.81	.54	2.35	.....
	99.96	100.15	100.28	100.22	100.08

* Carbon dioxide. † Total water.

are hydrated dolomitic lime, clays, finely ground sand, and finely ground feldspar. Some of these may be partly changed in time when in the concrete. The hydrated lime may be partly carbonated, especially on the surface; the feldspar may decompose by the leaching out of the alkalies; the sand will change but very little, if composed of a high-grade quartz sand; the clays will be very inert, although some theories have been brought forward which assume a very important role for clay when mixed with concrete; this is to the effect that the colloids of the clay protect the calcium compounds from quick hydration, and consequently prevent increase in volume due to chemical action." However, reliable data show that the addition of clay to concrete or mortar decreases their permeability considerably and even increases their strength to a slight degree. But the use of clay as balanced against the addition of extra cement

* Technologic Paper No. 3, p. 44.

to accomplish the same results should be carefully considered, especially in the light of a comparison of costs. For, reasonably good clay must be used, and unless cheaply obtained the balance will invariably be in favor of the cement. Plain blue brick clay and pure white Georgia clay may be used with good results as inert void fillers.

Use of Active Fillers. Active fillers consist of compounds which react with certain constituents of the cement, thus forming new compounds which are themselves inert and either barricade or fill up the voids. In most of these compounds on the market the active fillers form, but a small percentage of the compound proper as illustrated by the analysis in the first column of Table VI. "This compound was a white powder with a strong aromatic odor of Kauri resin. It was in fact partly a resinate of potash, which would be decomposed by the lime present to the corresponding lime resinate, which is comparatively insoluble. The great part of the compound is entirely inert, being china clay and hydrated lime.

"As, however, in themselves these materials are not waterproofing, but become so only as a result of a series of reactions, it would be better to use the result of these reactions directly and not depend upon something that may not always take place either wholly or in part."

Use of Proprietary Cements. Some proprietary cements are compounds made of Portland cement that has been altered by the addition of either stearates of lime, or soda and potash, sand, and other materials and specially treated until the mass becomes a water-repellent cement. Again, some waterproof cements are made by mixing about 5 per cent (by weight) of a lime-oil compound in clinker form, with Portland cement clinker and grinding them together. The powder formed is then used as ordinary cement, and results in a more or less dense concrete, not, however, independent of the necessary care in mixing and placing. Another form of compound of this nature consists of fish-oil boiled in hydrochloric acid, then mixed with burnt lime while slaking with water, the resulting product being a paste which dries and hardens as clinker. Another similar compound is made by combining a powdered resinate compound consisting of copal gum, hydrated lime and fine clay in proportion of 1 : 1 : 1 by weight with Portland cement, the use of which tends to make waterproof mortar or concrete. These compounds are also used for surface coatings as well as direct cements. When used as a direct cement, the lime-oil cement compounds depend for their impervious tendencies upon the formation of stearates of

TABLE VI.—TYPICAL ANALYSES OF ACTIVE FILLER, PORTLAND AND NATURAL CEMENTS

	Active Filler.	Portland Cement.*			Natural Cement.*			
		Lehigh District. Cement, Rock and Limestone.	Sandusky, Ohio Marble and Clay.	Chicago, Ill. Clay and Limestone.	Germany. Chalk and Clay.	Utica, Ill.	Louisville, Ky.	Rosendale, N. Y.
Silica	46.66%	19.06%	23.08%	23.62%	24.90%	27.60%	22.54%	27.30%
Alumina	16.71	7.47	6.16	8.21	8.00	10.60	8.24	7.14
Iron oxide	0.93	2.29	2.90	2.71	3.22	0.80	2.14	1.80
Lime	11.97	61.23	62.38	61.92	59.38	33.04	44.31	35.98
Magnesia	0.72	2.83	1.21	1.78	0.38	17.26	5.39	18.00
Sulphuric anhydride (SO_3)	2.73	1.34	1.66	1.32	1.16	7.42	2.82	6.80
Soda	0.34	....	....	....	....	2.00	....	2.88
Potassium oxide	1.44	....	....	....	....	....	....	....
Ignition loss	18.64	....	....	....	....	....	....	....
	100.14							

* Adapted from American Civil Engineers' Pocket Book, p. 407.

lime which are practically insoluble in water, and the presence of a large amount of hydrated lime, which also acts as a lubricant and inert void filler. On the other hand, the stearates of soda and potash are ordinary soap, readily soluble in water. With these soaps a reaction occurs when they are treated with water in the presence of cement; the soda or potash is dissolved and the more insoluble lime soaps are precipitated. If this kind of cement is used as a surface coating, however, it is doubtful whether the above reactions take place in a sufficient quantity of the soap to effect proper waterproofing properties before it is dissolved and washed off the surface. Experience indicates that in general, soap solutions do not bring lasting results as a waterproofing agent. Several cements of this nature have been analyzed by the United States Bureau of Standards with the results shown in Table VII.*

TABLE VII.—ANALYSES OF PROPRIETARY CEMENTS USED FOR WARERPROOFING

	Compound Used as Direct Cement	Compound Used as Coating* (Cement Content)
Silica	23.75%	22.40%
Alumina	5.96	7.98
Iron oxide	1.97	3.63
Lime	64.44	59.34
Magnesia	0.91	1.85
Sulphuric anhydride (SO_3)	1.21	1.15
Sodium oxide	0.11	....
Potassium oxide	0.73	....
Ignition loss	1.07	....
	100.15	
Carbon dioxide	0.52	2.16
†Organic (fat acid)	0.10	0.32
Water	0.45	0.93
		99.76

* This compound consists of Portland cement (27.73%) and sand (72.27%). The sand (all passing one-eighth sieve), is mixed with the cement, and is composed of quartzite and dolomite; there is also a trace of fat acids present.

† The organic is fat acids with a melting point of 52 deg. Fahr. and present as a lime soap.

Use of Integral Liquids. The liquids are mainly composed of metallic salts, such as chloride of lime; they also consist of oil emulsions and soap solutions, and solutions of paraffin in benzine

* Technologic Paper No. 3, pp. 41 and 47.

or benzol. But the paraffin solutions are usually not added to the gaging water, these being applied to a masonry surface with a brush as explained under the surface-coating system. The waterproofing properties of these liquids are derived from the formation of gelatinous coatings around the smallest particles of the constituents of the masonry. Of course, this would tend to decrease the strength of the concrete, and often does. There is also a coal-tar product used as an integral waterproofing from which the volatile oils have been almost entirely removed, and the remaining materials tend to bind together the particles of cement and fill the voids in the concrete. Some other compounds are composed of fish oil and water glass (sodium silicate). The fish oil, which is semi-drying, is slowly saponified by the lime of the cement, and the water glass forms a lime silicate, both actions, however, being incomplete, due to the insufficiency of lime present in the cement for such action. Analyses of a fish-oil compound and one of calcium chloride follow.*

Fish-oil Compound.		Calcium Chloride Compound.	
Soap	1.05%	Silica	trace
Oil	47.29	Alumina and iron oxide	0.25%
Ash water glass	11.64	Calcium chloride	27.19
Volatile (water)	40.02	Magnesium	0.04
		Water (and iron resinate 15%)	72.52

Use of Integral Pastes. Most pastes are soluble mixtures of secret ingredients which derive their waterproofing properties by the precipitation of insoluble materials in the voids of the concrete. Some also act so as to consolidate the mass by increasing its plasticity. These contain either fine clay, lime, or colloidal matter, or all of these.

Sometimes pastes are made by mixing a powder, such as alum, to the cement, and a soap solution to the tempering water. In making the concrete this paste is added, and the two constituents combine to form a stearate of aluminum which, as noted before, is a stable, water-insoluble, void-filling compound.

In the employment of integral pastes or any of the above compounds it is advisable first to investigate the efficacy of the materials by inspection of results accomplished on previous work. By submitting samples for analysis to qualified chemists, or by sending them to the United States Testing Laboratory the following necessary information can be obtained for a nominal cost: (*a*) effect on the strength of the concrete; (*b*) waterproofing properties when subjected to extreme ranges of temperature; (*c*) effect of common

* United States Bureau of Standards, Technologic Paper No. 3, p. 48

acids and alkalies on their waterproofing properties; (*d*) effect on steel reinforcement, i.e., if productive or preventive of corrosion, etc.

In all cases the manufacturer's written instructions should be followed with due observance, of course, to any special conditions arising on the work necessitating variation or change of manipulation.

Self-Densified Concrete

Definition, Purpose and Development. The system of waterproofing, or, more properly speaking, the practice of making impermeable concrete or mortar by means of self-densification, is, as the name implies, a process of proportioning the constituent materials and mixing them so as to create as dense a finished mass as possible. This is as difficult to obtain as it is finally effective in producing watertight concrete. The reason for this difficulty is that the requisite density is dependent upon varying factors, the ones most frequently militating against density being the lack of interest and inevitable fatigue of the labor employed together with the uncertainty of obtaining the specified quality and exact amount of materials for each batch without exceptional precautionary measures.

The self-densifying system of waterproofing like the integral system is adapted to any kind of mortar or concrete structure not subject to severe vibration, undue settlement or extreme variations in temperature, unless the movements due to such settlement or temperature changes are taken care of by properly located and waterproofed expansion joints. Its main purpose, however, is to eliminate the use of any form of waterproofing, because of the extra cost of materials, and the requisite time, labor, and attention necesseary in the application or incorporation of most forms of waterproofing compounds. If the energy spent in preparing and applying waterproofing materials were expended on careful proportioning, mixing, and supervision in making the mass concrete or the mortar, the engineer would obtain more nearly impervious masonry. The supervision required in either case, to obtain the best results, is in fact, about the same.

The origin of self-densified concrete is probably coincident with the origin of making concrete. In attempting to duplicate natural stone in strength, it was but one step further to attempt to make the concrete as dense as such stone. This probably led to the development of a form of cement so fine in itself as to have practically no voids whatsoever. Such a fine-ground cement carries more sand, and makes denser and more impervious concrete than the cement

of the old standard of fineness. This standard of fineness was 5 per cent passing a 2500-mesh sieve, as against 78 per cent passing a 200-mesh sieve of the present-day standard. But only in comparatively recent times was the further discovery made of the value of proportioning the constituents of concrete in such a manner that the voids of the stone, or largest aggregate, are completely occupied by the sand, the voids of the sand by the cement, and the whole united by the hydration of this cement in the presence of water. Though this is theoretically correct, in practice it is found necessary to use about 10 per cent of extra cement to obtain the best results; first, because of incomplete hydration of the cement; secondly, because of the practical impossibility of exact grading of aggregates; thirdly, because of insufficient mixing, tamping and supervision of details.

Methods of Making Dense Concrete. Concrete may be mixed either by hand or by machine, both methods, if properly applied, giving about the same grade of concrete, though the balance is always in favor of machine-mixed concrete. The work done by hand is likely to be uneven in quality, and some batches will be less thoroughlly mixed than others, while machine-mixed concrete is usually of a more uniform quality and is generally less expensive. Hand-mixed concrete is employed only when the quantity is small or when machinery is unobtainable, but not where uniformly dense and impervious concrete is an essential factor.

The fundamental requirements for obtaining self-densified mortar or concrete are: (1) destruction of the inherent porosity of the mortar or concrete; (2) scientific proportioning of aggregates; (3) careful supervision and good workmanship.

The inherent porosity of concrete is due partly to the fact that only about 20 per cent of the cement* used in making concrete is hydrated, or, in other words, acts as a cementing material, the other 80 per cent remains lying in the pores as so much inert matter, but only partly closing the pores; and partly to the fact that since every $62\frac{1}{2}$ pounds of water weight in concrete occupies 1 cubic foot of space, which amount of water, if lost by evaporation or drainage during the setting period, means 1 cubic foot of voids remaining in the mass. Again, improperly graded aggregate or poorly proportioned mixtures, or both, are very conducive to porosity in concrete and not so easily remedied. Too much water and too little mixing are factors in the workmanship which often results in porous concrete.

* See series of articles on microscopic study of concrete by N. C. Johnson, in Engineering Record, January, February, March, 1915.

The porosity due to the first two causes, i. e., insufficient hydration and excessive evaporation, may be reduced, first, by mixing each batch longer than is now common in practice (with the significant slogan in the industry of "a batch a minute"), and, secondly, by mixing with just sufficient water to obtain a medium or mushy consistency. Concrete of this consistency may be defined as a mixture of cement, sand, and stone or gravel of jelly-like consistency, which is not watery, but can be spaded and readily worked into place in the form. This consistency is illustrated in Fig. 21.*

Coarseness of sand and aggregate, is also effective in reducing porosity and absorption, although gravel seems to produce the denser concrete.† In fact, gravels are preferable to crushed-stone aggregate, particularly for underwater work, because they mix and settle in place more easily. Either crushed stone or gravel may be used, however, if carefully handled. But bank-run gravel should never be used, as its quality is not uniform.

Scientific Proportioning. The second essential requirement for the production of impermeable mortar or concrete is scientific proportioning. It is of the greatest importance that concrete should be made as dense as possible if it is to be made impervious, that is, that it should have the smallest practicable percentage of voids. This is best accomplished, or, at least, the various methods tending toward this result in practice are as follows:‡

(1) Arbitrary selection; one arbitrary rule being to use half as much sand as stone, as 1 : 2 : 4 or 1 : 3 : 6; another, to use a volume of stone equivalent to the cement plus twice the volume of the sand, such as 1 : 2 : 5 or 1 : 3 : 7.

(2) Determination of voids § in the stone and sand, and proportioning the materials so that the volume of sand is equivalent to the volume of voids in the stone and the volume of cement slightly in excess of the voids in the sand.

(3) Determination of the voids in the stone, and, after selecting the proportions of cement to sand by test or judgment, proportioning the mortar to the stone so that the volume of mortar will be slightly in excess of the voids in the stone.

* Technologic Paper No. 3, Bureau of Standards, Washington, D. C.

† Engineering News-Record, Vol. 79, No. 16, p. 740. 1917.

‡ "Proportioning Concrete," by Sanford E. Thompson, Journal, Association Engineering Societies, Vol. 36, April, 1906, p. 185.

§ Proportioning by voids has seemingly been proven fallacious. See Technologic Paper No. 58 of the U. S. Bureau of Standards, p. 39.

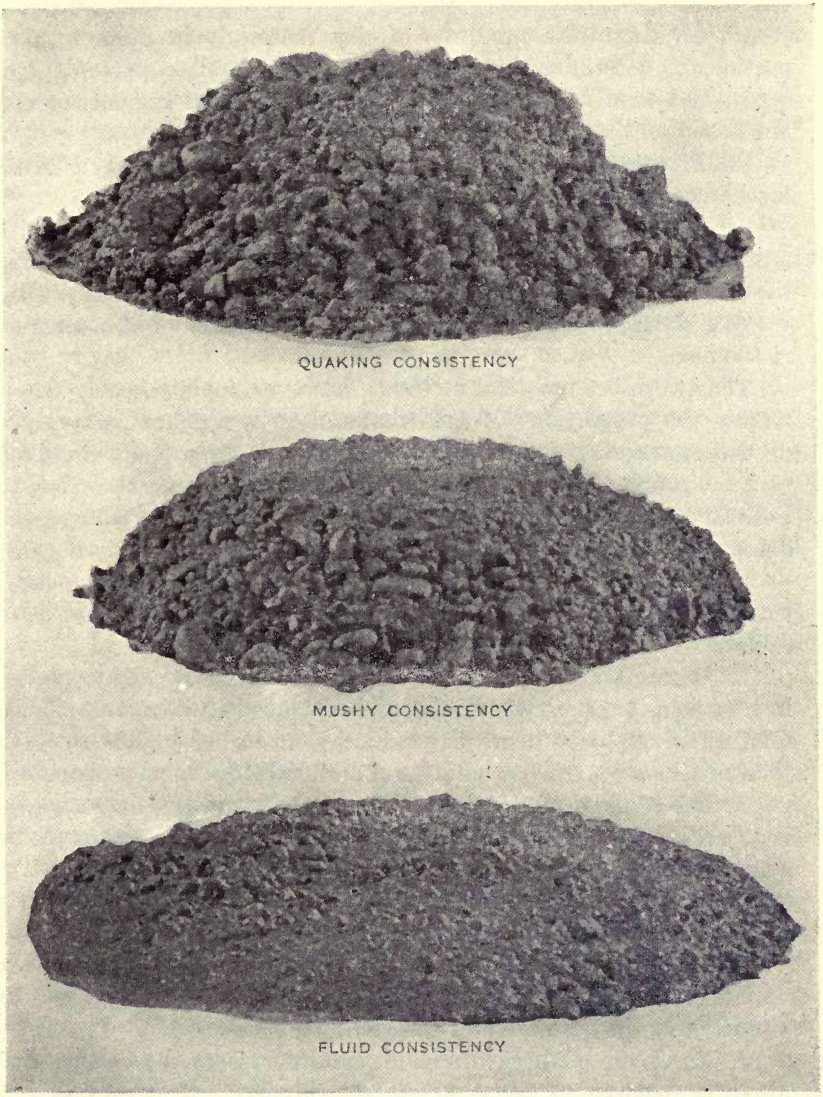


FIG. 21.—Appearance of Gravel Concrete of Three Consistencies. (From United States Bureau of Standards Technologic Paper No. 58.)

(4) Mixing the sand and stone and providing such a proportion of cement that the paste will slightly more than fill the voids in the mixed aggregate.

(5) Making trial mixtures of dry materials in different proportions to determine the mixture giving the smallest percentage of voids, and then adding an arbitrary percentage of cement, or else one based on the voids in the mixed aggregate.

(6) Mixing the aggregate and cement according to a given mechanical analysis curve. (See Appendix I.)

(7) Making volumetric tests or trial mixtures of concrete with a given percentage of cement and different aggregates, and selecting the mixture producing the smallest volume of concretes; then varying the proportions thus found, by inspection of the concrete in the field.

The two most practical methods, however, for accurately determining the proportions of each material is by mechanical analysis of the aggregates and volumetric synthesis, or proportioning by trial mixtures. The method of proportioning concrete according to Fuller's curve gives 1 : 1.41 : 4.34 as an ideal mix for producing the densest concrete.

From the above methods of proportioning the following laws, which relate especially to the grading of the aggregate, have been evolved:

1. Aggregates in which particles have been specially graded in sizes so as to give, when water and cement are added, an artificial mixture of greatest density, produce concrete of higher strength than mixtures of cement and natural materials in similar proportions.

2. The strength and density of concrete is affected but slightly, if at all, by decreasing the quantity of the medium size stone of the aggregate and increasing the quantity of the coarsest stone. An excess of stone of medium size, on the other hand, appreciably decreases the density and strength of the concrete.

3. The strength and density of concrete are affected by the variation in the diameter of the particles of sand more than by variation in the diameters of the stone particles.

4. An excess of fine or medium sand decreases the density and also the strength of the concrete, as will also a deficiency of fine grains of sand in a lean concrete.

5. The substitution of cement for fine sand does not affect the density of the mixture.

6. In ordinary proportioning with a given sand and stone and a given percentage of cement, the densest and strongest mixture is

attained when the volume of the mixture of sand, cement and water is so small as just to fill the voids in the stone. In other words, in practical construction, use as small a proportion of sand and as large a proportion of stone as is possible without producing visible voids in the concrete.

7. The best mixture of cement and aggregate has a mechanical curve resembling a parabola, which is a combination of a curve approaching an ellipse for the sand portion and a tangent straight line for the stone portion.

Grade of Workmanship and Supervision Necessary for Watertight Concrete. The third requirement is careful workmanship and supervision, particularly the latter, for obviously, where the engineers' directions are not followed, or orders are neglected; where supervision or inspection is lax, little can be done in the way of making dense concrete, in spite of willing and conscientious help. In this connection it is also well to remember that when inexperienced laborers or foremen are depended on to produce an impervious concrete, no scientific proportioning or prolonged mixing will turn the doubtful balance in favor of the concrete. To produce impervious concrete it is imperative to give strict supervision to details, and this phase is usually neglected by inexperienced labor. To accomplish these various objects, alert foremen and experienced workmen should be selected, and details of design and construction carefully attended to.

From the foregoing articles it may be seen that a 1 : 2 : 4 concrete is for all practical purposes impermeable, and that with scientific proportioning of ingredients and grading of aggregates, as outlined above, a 1 : 3 : 7 concrete can be made almost equally impervious. Further, the maximum density of concrete is obtained when the particles lay as close together as possible. Consequently its imperviousness depends upon the varying degree of roughness of the stone and sand, the relative sizes of stone, sand and cement, the proportionate quantities of the various sizes, the readiness with which the materials compact, and the amount of water used. The sizes and quantities being determined and adhered to, careful workmanship and cautious supervision will do the rest.

The use of these ingredients according to the varied but specific methods outlined, in no way alters the present standard methods of mixing and laying concrete. A variation though, in the general method of mixing concrete by machine must be noted because of its successful accomplishment in the matter of producing dense and impervious concrete. Contrary to the prevalent adverse opinion

of the practice of mixing concrete by first turning on the water and then dumping the aggregate into the mixer, this practice, slightly modified in that each material is put into the drum separately, starting with the water, followed by the cement, the sand, and finally the large aggregate, the drum revolving continuously, actually produces very impervious concrete. This practice is now resorted to in the manufacture of reinforced concrete water pipe.

Wherever the three essential requirements can be fulfilled and the suggestions for making them effective followed, there is but little need to add any waterproofing compound, providing the structure is not subject to vibration and other harmful physical influences. If it is subject to such influences, then the only systems well adapted for the waterproofing, especially on large engineering structures, under these conditions, are the membranous or sheet mastic systems, or, possibly, the surface coating system and in some cases, the grouting process. However, by the judicious arrangement and distribution of well-made and watertight expansion joints, all waterproofing may sometimes be eliminated, even in the non-rigid type of structure.

The general subject of the self-densification of mortar and concrete is treated exhaustively in standard works on concrete, and for more particular and detailed information, these may be consulted to good advantage.

Grouting Process of Waterproofing

Definition, Purpose and Development. Waterproofing by the grouting process means the placing (usually) of a very wet cement mortar behind and around a finished iron or masonry tunnel or other underground structure, injected through the walls or some portion of its body. The mortar or grout is forced, generally by means of a pneumatic grouting machine, through cracks, joints, or pipes suitably located in the structure, until refusal, or until there is evidence of the grout having filled all the seams in the rock, or permeated the ground in the immediate vicinity of the structure. The purpose of this is to force the ground water to find or make new channels for itself, so that it will not come in direct contact with the structure, which may not be sufficiently watertight in itself to prevent seepage. The mortar or grout is, of course, in itself very impervious. This follows from the richness of the mixtures used, in many instances being nothing more than a neat cement. In fact, such mixtures, that is, either neat cement, grout, or mortar, form the most imper-

vious materials, and constitute the best waterproofing mediums if applied in the proper place and manner. For the grouting process, these materials are well adapted, and serve their purpose admirably.

This system or process of waterproofing is well adapted for solidifying masonry, various soils * and fissured rock, for sinking wet construction shafts, and for driving tunnels in unstable and water-bearing material, for cutoff walls and in general where great water pressures are to be resisted by the finished structure as, for instance, around tunnels underneath river beds. Grout is also used in tunnel headings which must pass through water-bearing ground, to fill the voids in the dry packing over a tunnel arch or elsewhere, to cut off heavy flows of water from cracks, seams, and fissures in the rock about the tunnel or its shafts, in the solidification of rock and quicksand at dam sites, and to insure a watertight contact with, and the complete protection of, steel work imbedded in the masonry. In fact the grouting process has a wider field of usefulness than is generally known.

The grouting process originated or was invented before 1891, but was only patented in that year. The inventor, Mr. Robert L. Harris, set forth many of the possibilities of this process, and to-day it is a recognized engineering procedure and is used on practically all tunnel construction, though somewhat modified in method. One of these modifications, perhaps the most radical and of very recent origin, consists of a pneumatic concrete machine that mixes, conveys and places the concrete in one continuous stream and operation, producing a reasonably dense, and impervious concrete. This process eliminates dry packing over arches of tunnels, permits the placing of the complete ring of tunnel or lining but does not readily fill up seams or fissures in the natural rock. This particular apparatus is still undergoing improvement and promises fair to be a most important addition to the engineer's equipment of machines for making and placing dense mortar and concrete. The grouting process in general will have a wider field of usefulness when its operation and manipulation, its simplicity and effectiveness are better understood, and the apparatus perfected, resulting also in greater economy in its application.

* In sinking a large steel caisson shaft for constructing a tunnel under the East River to connect the new subways between Brooklyn and Manhattan, New York City, the bulkheads of the caisson contained a number of 2½-inch diameter openings, capped during sinking, and used for consolidating the surrounding material by grouting. Public Service Record, Vol. 3, No. 3, March, 1916. Published by the Public Service Commission, 1st District, State of New York.

Application of Grout for Waterproofing. To secure good results from the grouting process, great care must be exercised in conducting the work. This work is most advantageously carried on at a reasonably low temperature. Attention to details and a thorough understanding of the nature of the problem at hand are necessary. In the case of driven tunnels, for instance, great judgment and care are required in panning off running water so that none of it will come in contact with fresh concrete; and such considerations as the best method of drilling and placing holes for grouting, the proper consistency of the grout mixture, the best cement to use, what injection pressure should be applied, the best means of producing and controlling the flow of grout, are matters vital to the success of the process. But these are not difficult to determine as a rule by the performance of a few preliminary field tests.

In tunnels grouting under pressure is not done until some time after placing the complete ring of masonry lining at the location to be grouted, except to reduce leakage in wet ground, or in connection with sections of masonry lining built to control such leakage or to support wet and heavy ground. Generally, grout is mixed as thick as can, with certainty, be made to completely fill the voids. Good proportions for grout are 1 : 1 (or $1\frac{1}{2}$) : 1. Sand or stone dust and either Portland or natural cement can be used to equal advantage. Grouting should be carried on continuously at any particular seam or void until completed, without intermission sufficient to allow the grout to take an initial set. The grout should be delivered uniformly and steadily to avoid occluding air in the interstices of the dry packing. This is usually accomplished by using two grouting machines so that while one is shooting grout the other is being charged. This is especially necessary where large seams or voids in rock are to be grouted.

For filling large voids thick grout is best, but for small cracks and fine seams a thin mixture should be used, as, for instance, a mixture so lean that the water will carry the cement as far as possible into the fine seam and so avoid blocking up close to the drill hole.

In tunnels through rock, all voids over the arch should be filled without requiring the grout to travel a great distance, not more than 25 feet after leaving the grout pipe. Grouting of any section of tunnel should begin at the bottom and proceed uniformly upward, unless some other order is found more desirable. If the upper ends of each series of grout pipes are at different elevations, the grouting should invariably begin at the lowest pipes, and no higher pipe connected until the grout from a lower pipe begins to flow out of it (see

Figs. 22 and 134). Cutoff walls of masonry are sometimes built tight against the roof and across the arch of the tunnel, dividing the space above the arch into sections. This makes more certain the filling of the voids in the packing of that section, except in unsound rock where the grout can flow around the cutoff, or where the cutoff has not been properly made.

Grouting is usually considered completed when no more grout can be forced into the seam, void or dry packing space under the required pressure.

Cement and Sand for Grouting. Various materials are sometimes found effective for grouting purposes. For instance, muddy water, liquefied clay, soft clay, and ground horse manure have been used

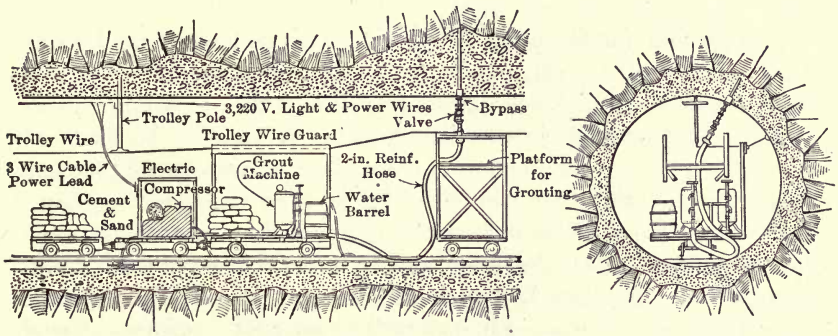


FIG. 22.—Electric-driven Compressor Connected to Grout Mixer, Showing Arrangement of Equipment and Use of Grout Pipe.

alone or with cement for sealing fissures in rock or cracks in massive concrete. But grout alone is usually and most extensively used with marked success on all kinds of underground structures, success depending, however, on the care and attention exercised in applying it. Though Portland cement is the most commonly used, natural cement may be used. Sand cement is also used and is found very efficient because it not only sets as well as Portland cement but seems to mix better and produce a smoother flowing grout.* However, almost any standard commercial but preferably quick-setting cement is suitable for grouting.

The best sand for grout is that grade which will pass approximately 100 per cent through a sieve having 64 openings per square inch and approximately 45 per cent pass through a sieve having

* Engineering News-Record, Vol. 78, No. 13, p. 627. 1917.

1600 openings per square inch. If it is desired to use stone screenings instead of sand it should be the finest obtainable or such as will pass at least 60 per cent through an 8-mesh sieve, 85 per cent retained on a 50-mesh sieve and 90 per cent retained on a 100-mesh sieve. The quantity of water necessary to form the mixture depends on the physical condition of the ground, rock or masonry to be grouted as well as upon the condition of the sand or stone screenings. It is always best to commence with a very liquid mixture, say one part of cement to five or seven parts of water, by volume, increasing the amount of cement untill a 3 : 6 to 3 : 7 (sand : water) mixture is obtained. But it is not possible to adhere to any set rule in grouting, therefore the operator should possess both judgment and experience if the greatest efficiency and economy are looked for.

Equipment for Grouting Process.* The best equipment to use for forcing grout into the spaces to be filled depends upon the pressure necessary to make the grout travel, and the consistency of the mixture best adapted to the size and kind of voids to be filled. If a considerable yardage of grout is required a large capacity equipment is best, but where a small quantity is to be placed, especially under high pressure, a different equipment is necessary to secure the best results. In the past, and to a certain extent at present, grouting has been done by pouring the mortar or grout through pipes arranged in such a way as to secure the necessary pressure. Generally, however, more pressure than that afforded by the head of grout alone is required.

The equipments ordinarily used at the present time are as follows: (1) Reciprocating pumps furnishing a continuous flow with independent means of mixing the grout; (2) Pneumatic mixers and placers, which are of two classes† (*a*) paddle mixing and air ejecting, (*b*) air mixing and air ejecting; (3) paddle mixing and water ejecting. A paddle mixing and air ejecting type of grout tank has been extensively used on shield-driven tunnels. This type is well adapted for placing large quantities of grout, as in grouting dry packing behind tunnel linings, especially over the arch.

A tank of the air-mixing and ejecting type was used very largely on the work of the New York Board of Water Supply, particularly in grouting shafts and pressure tunnels. To counteract the extremely high head over the Hudson crossing, a Cameron pump was used to force water into the grout tank. This raised the pressure as high

* Engineering News, May 6, 1916, Vol. 75.

† Developed and patented by William Lester Canniff in 1907.

as 600 pounds per square inch, which was sufficient to force the grout in against the external head.

Great care must be exercised in the manipulation of these types of grout mixers as, for instance, to shut off the discharge valve the instant the last bit of grout leaves the tank; otherwise an afterblast of air follows, which stirs up the grout, air collects in the spaces to be filled by the grout and is displaced only with great difficulty.

The paddle-mixing and water-ejecting type of grouting machine* is a newly invented modification of the ordinary grout mixer. This water-ejecting type seems better suited than the air-ejecting types, when great pressure is required, to accomplish the ejecting process against a great head. This water-ejecting grout machine can be and is also used for low heads with ordinary pressures. Its main object, however, is to provide an inelastic driving power, formed by a fluid (water) piston, for forcing out the grout. As built, this machine is more easily and certainly controlled and dispenses with air compression when water under a head is available. Its limited use does not yet permit a statement of its relative efficiency when compared to the air-using mixers.

The following description of the equipment employed in grouting the City Tunnel (Manhattan) of the Catskill Aqueduct is particularly interesting because it was evolved there and used with remarkable success. It is in fact a typical equipment for all deep tunnel grouting. Figs. 22 and 23 show the arrangement of the plant commonly used on the Catskill Aqueduct, and which was adopted in some sections of the City Tunnel. Air, piped from the compressor plant on the surface, was delivered directly to the grout tanks at a pressure of from 80 to 100 pounds per square inch for the low-pressure work. When the grouting required higher pressure the air was further compressed to 200 or 300 pounds per square inch by means of an auxiliary air-driven compressor or " booster," supplied from the compressor at the surface. Fig. 22 shows a type of equipment in which the low-pressure grouting was carried on as usual with the air furnished from the surface compressor plant. The high-pressure grouting was also done with a small compressor driven from the lighting or power circuits. With a plant as shown in Fig. 23, both the low- and high-pressure grouting was done with the electrically driven compressor in the tunnel. The adoption of this equipment, in which the compressor in the tunnel is operated only when grouting is actually being done, makes unnecessary the more or less continuous operation of the large compressor plant on the surface and effects a

* Patented by S. C. Hulse, February, 1917.

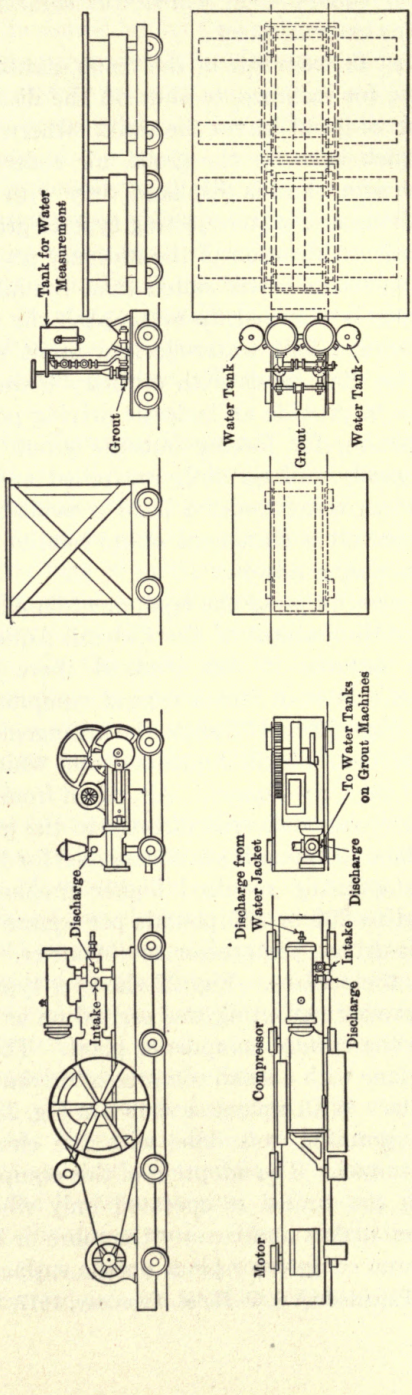


FIG. 23.—Grouting Equipment Used on the City Tunnel of the Catskill Aqueduct, New York.

further economy in avoiding the piping of compressed air through the tunnel for grouting work.

Many good details of operation and experience with the grouting process are described in a series of articles by Mr. James F. Sanborn,* Division Engineer, Board of Water Supply, New York, which are well worth persual by readers contemplating similar work.

Steam-pressure Concrete Mixing and Placing Machine. A new machine embodying the principles of both the grout mixer and cement gun has recently been developed and used for making watertight concrete direct by materially increasing its density during placing. This machine is called a concrete atomizer and the details of its operation are as follows:†

The machine illustrated in Fig. 24, *A*, can make concrete weighing about 170 pounds per cubic foot. Superheated steam at from 75 to 80 pounds pressure is turned into the mixing chamber while the concrete is being thoroughly mixed by mechanical means. The mixture is then discharged through an outlet, and a fresh supply of superheated steam takes it to the form at high velocity through a special hose, which is provided with a nozzle opening which can be instantly increased to the diameter of the hose in case it is plugged. Where conditions prevent the use of steam, superheated compressed air gives almost as good results. Fig. 24, *B*, shows a plant where high-pressure steam is supplied from a locomotive, passed through a reducing valve, and superheated to supply the mixer. The superheating effectively prevents condensation of water in the stream of concrete being delivered from the nozzle to the point of work, and enables the workman to see the face upon which he is playing the stream.

The pressure and superheating produce a concrete of considerably increased strength, while the force with which the mixture is applied gives it great density. A thin slab placed in this way has been found to be waterproofed under high water pressure. When the amount of mixing water is properly regulated little aggregate is lost by falling from the working face, and sections 1 foot in thickness have been placed in continuous operation on vertical walls. One of the photographs shows this machine at work repairing a concrete retaining wall. It has also recently been successfully employed to reline a badly leaking tunnel with gravel concrete about 5 inches thick.‡

* "Grouting, an Effective Remedy for Stopping Leakage in Tunnels and Shafts," Engineering Record, April 15, 22, and 29, 1916.

† Invented and described by Harold P. Brown in Journal of American Concrete Institute, Vol. 111, No. 7, July, 1915.

‡ Proceedings American Concrete Institute, Vol. 12, 1916.

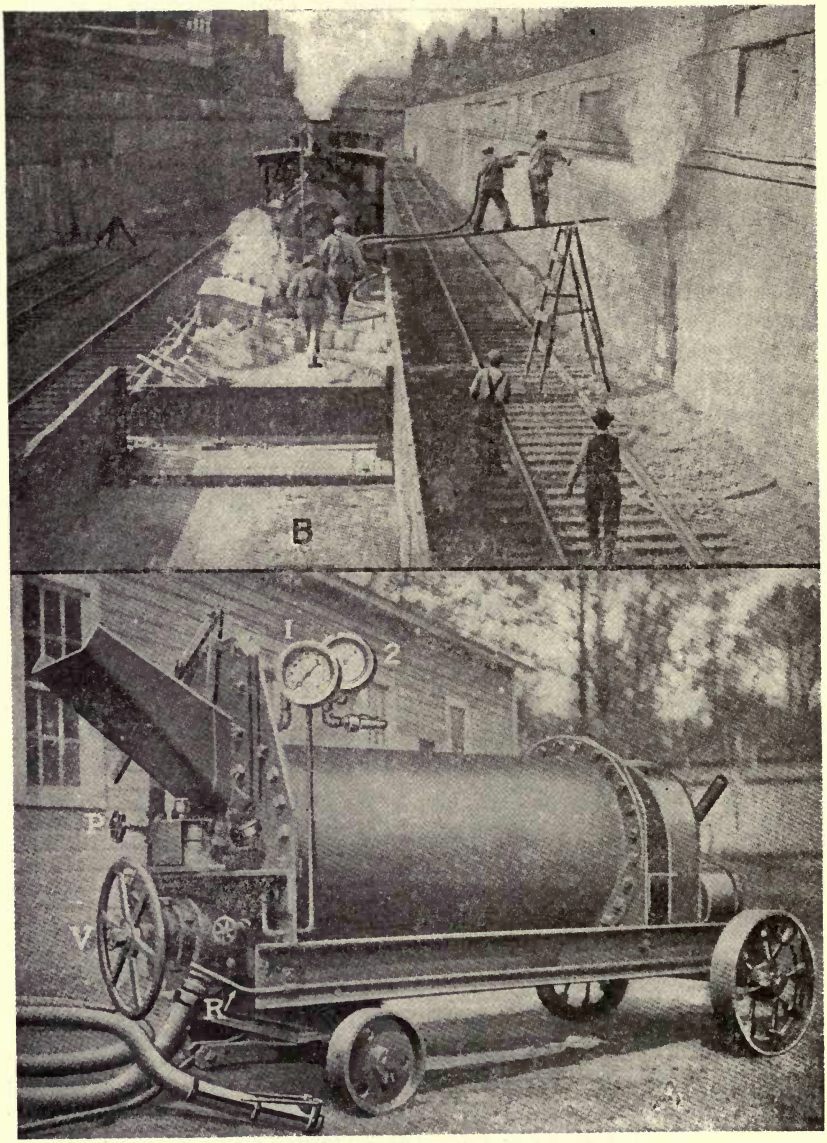


FIG. 24.

A. "Concrete Atomizer," which Turns Out Concrete under 80-lb. Steam Pressure.

B. Mixer Outfit at Work on Delaware, Lackawanna & Western R. R. Retaining Wall, Newark, N. J.

CHAPTER III

IMPERVIOUS ROOFING

Impervious Roofing Defined. The subject of impervious roofing is vast and complex, and we can only hope to cover its more general aspects with as much detail as is consistent with the practical limits desired for this chapter. The term " Impervious Roofing " is taken to mean those materials which are used as a topmost covering for any form of building construction and whose main function is to create a watertight roof. These materials always require properly constructed supports regardless of the character of the roofing or structure. Impervious roofing, however, does not include the supports, such as trusses, beams, purlins and rafters, but does include everything else such as sheathing boards, masonry tiles and slabs or other suitable sheathing materials, which are placed upon the roof supports for the double purpose of providing a uniform and continuous surface for receiving the waterproofing materials and adding to the protection of the interior from the elements. Rain, hail and snow are, of course, the particular scourges which create the necessity for making roofs absolutely watertight. The cost of roofing depends on so many different factors, that no worth-while estimate could be given as a general indication of the relative saving to be expected from the use of the types explained below. However, one thing should be borne in mind, namely, the annoyance and maintenance expense occasioned by leaky and short-lived roofs, are hardly compensated for by any possible saving in first cost. The following considerations should guide the selection of a roofing:* (1) Chance of leaks due to character of construction; (2) Probable life, including chance of damage by the elements and by wear from other causes; (3) Fire-resisting value; (4) Cost of maintenance; (5) Cost of materials; (6) Cost of laying.

The simplest form of roof is the primitive flat roof of the Orient made with cross beams, thatch, and a heavy layer of stamped clay, which made the roof more or less watertight. In central Syria and

* American Railway Engineering and Maintenance of Way Association, Bulletin No. 131, January 19, 1911.

in Egypt important buildings were roofed with beams and made watertight with slabs of stone. The Greeks used mainly low-pitched, gabled roofs protected with tiles of marble or terra cotta. The Romans were the first to use domes of brick or concrete covered with cement and lead sheeting for watertightness. On elaborate structures the roofs were covered with tiles or with bronze plates. In the mediæval cathedrals the roofs, which invariably had a very steep pitch, were for the first time in history sheathed with boards, then covered with slate, tiles, sheet copper or lead. The Italian classic type of roof was made nearly flat; and this type now predominates in tropical and subtropical climates. Steep roofs quite obviously predominated in regions of much rain or snow, as in northern countries, and continue to do so. Most modern roofings have not the same architectural beauty as those of ancient classic types, but they are more economical and efficient, also more varied and numerous in material and design than the old roofings. Some of the more important ones will be considered separately in the following articles.

Properties and Application of Shingles

Wood Shingles. For securing watertight roofs, many materials are now in common use, all of which fall under four general heads of roofing, namely: the shingle roof, the tin roof, the felt roof (also called the composition of built-up roof), and the functional roof. The oldest and most commonly used of these roofings is the shingle roof. Wooden shingles are universally used for this purpose. These are made of various woods, such as cypress, redwood, cedar, juniper, white pine and spruce; this also being the order of their durability. Cypress is the most durable of wood shingles, though, as with all other woods, it is only the heartwood that shows greatest durability.* On the other hand redwood is much less inflammable than any of the others and spruce is the cheapest. Wooden shingles are usually packed in bundles (four of which constitute a "thousand," or the equivalent of one thousand shingles 4 inches wide) sawed to dimension sizes, which range from 4 to 6 inches wide and 16 to 24 inches long, or in random sizes, which range from $2\frac{1}{2}$ to 16 inches wide and 16 to 24 inches long. Wood shingles are easy to apply, being fastened to the sheathing boards with two or three nails driven into the part that will be covered by the exposed portion of the superimposed

* Cypress shingles were laid on a roof of a building in Greenwich, Conn., in 1640 and were serving well 250 years afterwards.

shingle. Unfortunately it is almost impossible to secure nails that will not corrode before good shingles will deteriorate, hence the shingles become loosened and displaced. The use of pure iron nails, rather than galvanized iron nails, will reduce this hazard to a minimum. No shingle should show more than one-third of its face to the weather. For the number required and the covering area of shingles, see Table XXXVII. For protecting wooden shingles from rapid incineration and deterioration, they are usually dipped into fireproof liquids, such as solutions of sodium silicate or aluminum sulphate, or coated with a wash mixture composed of lime, salt and fine sand or wood ashes. The sodium silicate, however, is readily soluble in water hence it will wash off unless the shingles are given a top coat of oil or paint; and the lime-salt-sand solution will not stick long unless also covered with a coat of oil or paint. The most effective and in the end the economical way would be to paint the shingles with a zinc borate paint. This paint is also remarkably fireproof. For preserving purposes such salt solutions as zinc chloride and sodium fluoride; or such oils as carbolineum and dead oil (creosote oil) are much used. The shingles are dipped in either of these for a period determined by experiment but usually depending on the grade of wood used. If creosote oil is objectionable, then besides the above salt solutions a solution of persulphate of iron of 2 to $2\frac{1}{2}$ deg. Baumé, can be substituted. But if the persulphate of iron solution is used then it is advisable to top coat the shingles with hot, raw, linseed oil. Often, however, besides receiving preservative treatment the shingles are painted or stained to create a pleasing effect. Since dipping the shingles is mainly for their preservation, they are completely submerged in the liquid, but in painting them, which is mainly for appearance, only the weather portion of the shingles is coated. However, unless this is done with the greatest care, it would be better to paint the whole shingle, because otherwise dry-rot will hardly be prevented. For shingles that are merely to be stain-treated (they can be stained almost any color), the staining is best and most durably applied by dipping.

Slate Shingles. Next in general use are slate shingles, especially the black and the red varieties, but various shades of green and gray are also used. These are supplied commercially in thicknesses of $\frac{1}{6}$, $\frac{3}{16}$, and $\frac{1}{4}$ inch, increasing by $\frac{1}{8}$ inch, to 1 inch. Slate should be hard and tough, and have a well-defined vein, which must not be too coarse; if the slate is too soft, it will absorb moisture, if too brittle, it cannot be cut and punched without splitting, and it will easily be damaged by walking on the roof. A clear metallic ring when the

slate is struck is an indication of its soundness; a muffled sound indicates a cracked or soft condition. For the number of shingles required per square of roof surface, see Table XXXVII. Slate shingles are usually attached to the sheathing over two or more plies of treated felt. Sometimes this felt membrane is cemented with a bituminous binder. Occasionally the slate shingles are laid up in neat cement, or rich cement mortar, but more often they are nailed to the sheathing boards like wood shingles (see Fig. 25). On irregularly shaped roofs and in locations near hips and valleys and flashings great care and skill are required in laying the shingles so as to avoid leaks. For these places tin is often used but copper or sheet lead are best adapted for the purpose.

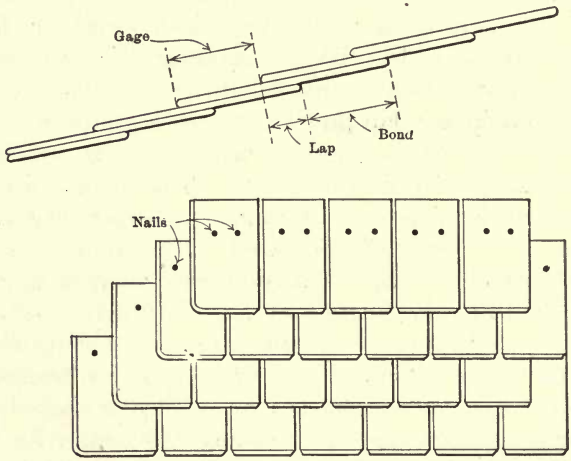


FIG. 25.—Typical Details of Slate Roofing

Slate shingles are often attached to concrete or porous terra-cotta roofs, by being nailed directly to the surfaces. This is poor practice especially on roofs having the minimum allowable pitch. A means for attaching them more securely is to nail $1\frac{1}{4}$ by 2 inch-wood strips to the outer face of the concrete or terra cotta, the strips being set the proper distance apart to receive the slate shingles, and then plastering between the strips with cement mortar. This gives a good nailing base for the roofing. Among the best impervious roofings that can be put on a flat or moderately inclined roof is one of slate shingles, laid over a membrane of five plies of treated felt. The membrane is applied with bituminous binder as for a felt roof, and the slates bedded on the membrane in cement

mortar.* For this arrangement the shingles are thicker than ordinary and laid butt-joint fashion.

Tile Shingles. Next in order of usage are tile shingles. Clay tiles were used before historic times, and, of course, all down the ages there has been considerable improvement in the product. Not, however, till 1851, when the first tile-making machine was invented, did the manufacture of clay tiles assume a real industrial aspect, as previously all tiles were made by hand. To-day the tile industry is extensive and exists practically in all countries of the world. Tiles are manufactured in various sizes and forms and of such materials as clay, shale (vitrified tiles), cement mortar, and even reinforced concrete. (See Figs. 27, 28, and 29.) Clay roofing tiles properly made, that is, well-glazed and hard-burned throughout, cannot be excelled for durability. The application of vitrified tiles often depends on their form. Some are curved on both ends and hook on each other downward from the ridge tile, which is straddled on the ridge pole; some are rectangular (the usual dimensions being $1\frac{1}{4}$ by 6 by 9 inches), and of various shades, such as red, black, green and gray. It is harder to get a tight roof with ordinary tile than with slate, but the interlocking shapes that have been devised give very good results in this respect. Sometimes the tile is imbedded in a plastic cement or in cement mortar upon an underlying three- to six-ply built-up felt roof, replacing the gravel. In fact, this scheme has become the practice for roofs of modern high and expensive buildings. Flat porous tiles similar to the above, but of larger size are usually attached in the same manner as slate shingles. Sometimes the large-size tile is laid directly on steel or wooden purlins, which must be spaced to suit the length of the tile.

The cement tiles are of various shapes and sizes; those shown in Fig. 28 being an extensively used type. They are, of course, fireproof as well as waterproof, strong and practically permanent. They are usually made so as to lay directly on the purlins.

The reinforced concrete roofing tiles are mostly home made, so to speak. They can be made anywhere in all sizes, shapes and colors, hence are very adaptable for special purposes. Reinforced concrete roofing tiles were extensively used on nearly all superstructures of the New York Catskill Aqueduct. Because of their relative high cost their use is limited to elaborate and expensive structures; but because of their permanence and serviceability they should have a wider usage. In this connection the following brief suggestions for making reinforced concrete tiles will be of material aid.

* Kidder's "Architects and Builders Pocket Book," p. 567.

Success in using reinforced concrete roofing tiles depends on the care with which they are made, handled and placed. The first requisite is that they be made impervious to water and as dense and strong as practicable. The thickness of tiles varies from $\frac{3}{4}$ inch to 3 inches, depending on appearance and extraneous functions. The

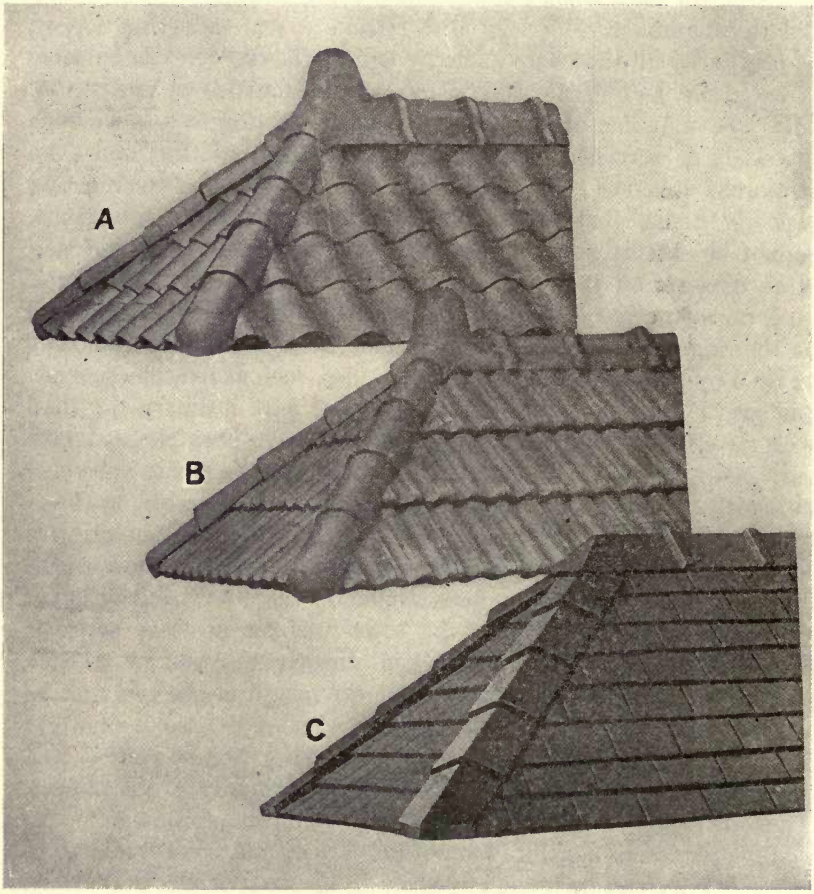


FIG. 27.—Baked-clay (Vitrified Tile) Roofing, Showing A, Spanish; B, German; and C, Closed-shingle Types.

thickness of pan (flat) tiles (as used on the above mentioned work*) except at the ribs, or along the edges, was approximately $1\frac{1}{8}$ inches, being nowhere less than 1 inch, while the average thickness was not

* New York Catskill Water Supply, Type "A" Reinforced Concrete Roof Tiles.

to exceed $1\frac{1}{4}$ inches (see Fig. 29). In placing the tiles upon the steel frames of the roof (and steel frames are preferably used for their support so as to obtain the necessary rigidity), the steel should be covered with mortar or other suitable coating material for protection against corrosion. It is important that this covering be neither chipped, cracked nor otherwise injured. Flashings for tiles about

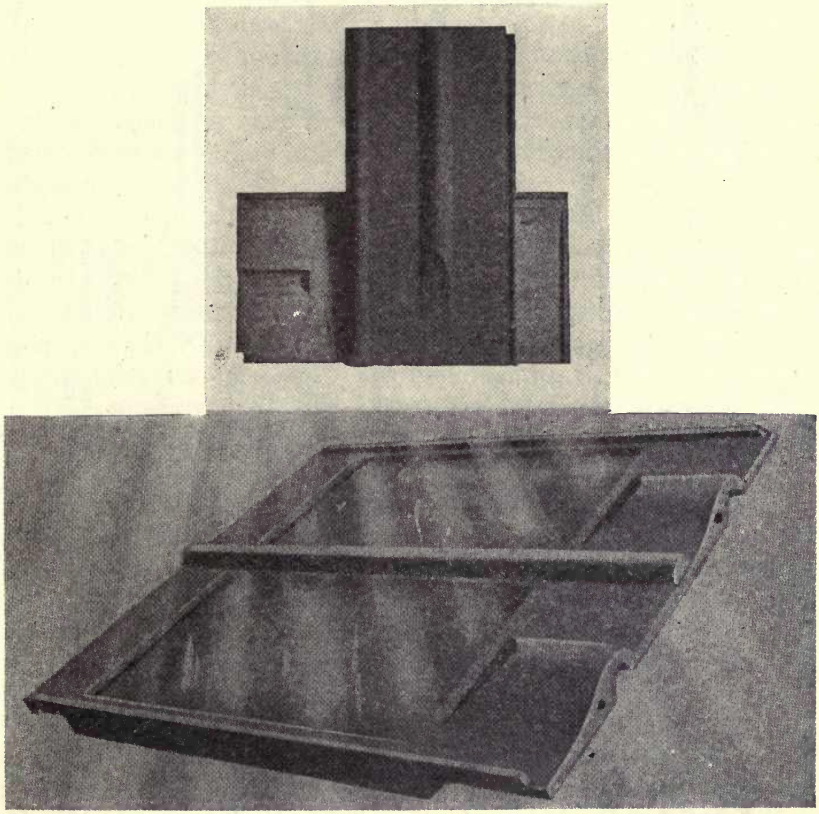


FIG. 28.—Types of Cement Roofing Tile.

the chimneys should preferably be of sheet copper, such as weighs 20 ounces per square foot.

The best aggregate for concrete tiles is clean quartz, which contains both fine and coarse particles of suitable limiting sizes and is satisfactorily graded. All aggregates, however, should not contain sufficient loam or clay, or other objectionable matter, to render them unsuitable for making an impervious and uniformly clean-looking

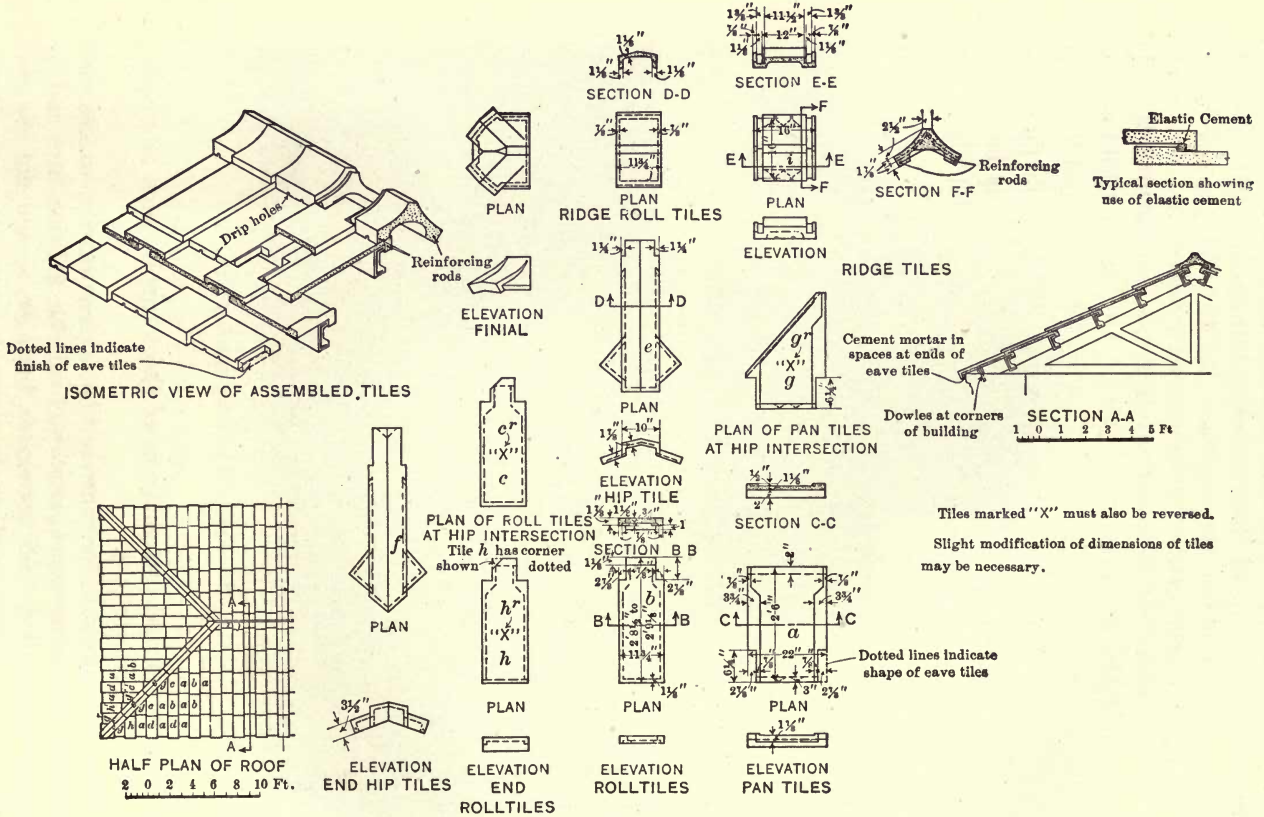


FIG. 29.—Details of Reinforced Concrete Roof Tiles Used on Structures of the Catskill Aqueduct.

tile. For best results it is important to use clean water and to form a medium consistency concrete. In general the mixture may be approximately in the proportions of 1 : $2\frac{1}{2}$ to 1 : 3, the aggregates being measured by weight or volume, as found practicable. It is important to thoroughly mix the concrete in a good mechanical mixer, except that very small quantities may be mixed by hand. Concrete mixing by machine should be continued for at least ten minutes. No tiles should be made of retempered concrete. Where it is desired to tint the tiles, mineral coloring materials may be added during the mixing, but if the bottom surfaces are to be exposed inside of a building they should preferably be a very light gray or white. The top surface of tiles may be tinted by the surface application of a suitable paint.

Steel reinforcement for concrete tiles should be ample, preferably of the mesh fabric variety, firmly fastened at each intersection and properly placed. For reinforcing the ridge, hip, rib and finial tiles or other special shapes and the bearing lugs of pan tiles, steel rods about $\frac{1}{4}$ inch in diameter will be very useful in addition to the mesh reinforcement. The best practice is to put the steel in the lower part of the tile and every part of it at least $\frac{5}{16}$ inch from the surface. The reinforcement must be placed in exact positions specified by design, and held in position so as to prevent displacement while the concrete is being deposited and while it is setting. If the concrete is not sufficiently wet to thoroughly coat the steel with cement, it is advisable to coat the steel with cement grout as it is being placed in the form or immediately before placing.

After fabrication the tiles should be seasoned; that is, in order to avoid all manner of cracks, the tiles, on removal from the forms, should, during the first month, be kept constantly moist. It is very important that all the tiles should be true to the shapes required by the particular design; especially is it important to see that the flat tiles are not warped. Particular attention is also necessary for making those edges which bear on the surfaces of other tiles so true and smooth as to form good joints. Variations from any dimension ought not to exceed $\frac{1}{8}$ inch. The tiles should be adjusted in place so as to give close joints where exposed to the weather, and so that each tile will have a satisfactory bearing. The exposed spaces between the soffits of the eaves tiles and the cornices should be pointed smooth with Portland cement mortar, which may be made to match the tiles in color. All joints should be made permanent with an elastic roofing cement. Tiles having unevenness,

voids or other objectionable imperfections which would reduce their impermeability, should not be used.

To test the permeability of concrete tiles, at least two seasoned pan tiles should be placed separately in a horizontal position, top up, and subjected over the area which would be exposed in the roof, to a 3-inch depth of water for seven consecutive days, after which a well-made tile should not show any dampness over the bottom. The strength of tiles may be tested by placing flatwise, horizontally, top up, a tile not less than twenty-eight days old, on rigid supports, one near each end of the tile and extending across its full width. Thus supported, a tile as illustrated in Fig. 29 should be able to support a central load of at least 600 pounds, applied gradually, bearing across the whole width of the tile.

Prepared Shingles. Then there are what, for want of a better name, are called "Prepared Shingles."* Indeed, these shingles are fast becoming a very staple roofing material. Prepared shingles are composed of various materials, such as asbestos fiber compressed into boards of various thicknesses, sizes and shapes: or of two or three plies of wool and rag felt, saturated and coated with various grades of asphalt, made, smooth or rough-surfaced and cut into shingles 8 by $12\frac{1}{2}$ inches or 8 by 16 inches which are the two standard sizes; or of a thick, treated, wool-felt, surfaced either with fine sand cr carefully screened grit, but sometimes with mica flakes, or stone screenings (see Figs. 30 and 34) such as slate, feldspar and silicate, whose varied colors create pleasing roof effects. In the felt shingles, it is, of course, the asphalt (or coal-tar pitch) treatments which give the weather-resisting qualities to them. If unsurfaced, they are of light weight and sometimes the asphalt-treated shingles tend to disintegrate or the coal-tar pitch hardens and the shingles become brittle on exposure. Hence, the final surfacing with a layer of mineral matter serves a threefold purpose.

In view of the growing importance of prepared shingles, the following instructions for applying them will be found helpful:

The sheathing boards should be laid closely and securely nailed. It is necessary to see that the surface is clean and free of all projecting nail heads or other obstructions. On particular work, it is good practice to first cover the sheathing boards with a single ply of building paper or treated felt. One row of shingles is laid lengthwise along the entire lower edge of the sheathing, extending $\frac{1}{2}$ inch over the edge of the sheathing or inner edge of the gutter. These must fit closely and each lower corner nailed, driving the nails 2

* Prepared shingles were originated in 1901 and first marketed in 1910.

inches from the lower edges and ends. One nail is driven half way between the two, thus using three nails to each shingle on this row. It is best to use 1-inch galvanized nails with large, flat heads about $\frac{1}{2}$ inch in diameter.

The regular course should begin with a full-sized shingle, as shown in Fig. 30, laying same parallel to, and flush with, the outer edge or vertical end of the roof. The lower end is flushed with the first layer, allowing $\frac{1}{2}$-inch space between the shingles. The course is thus continued, using two nails to the shingle, driven $4\frac{1}{2}$ inches from the lower edge. The second row is thus begun with two-third-sized

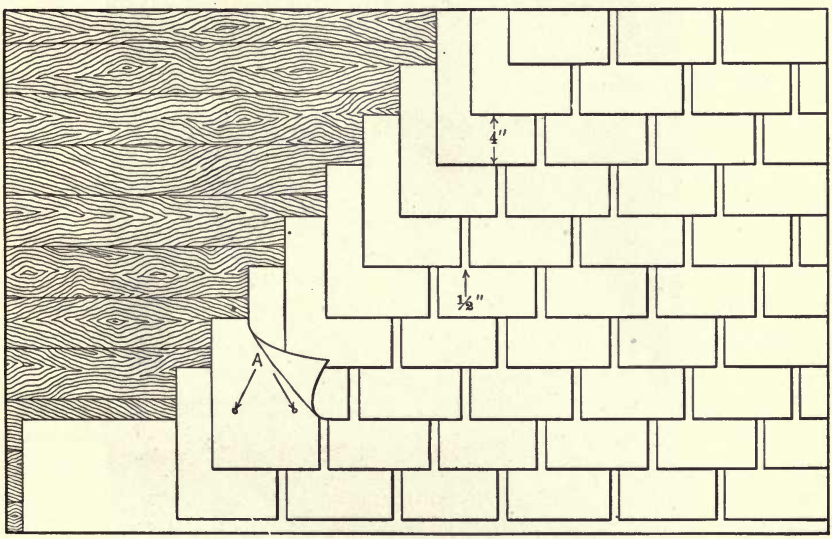


FIG. 30.—Undersurfaced, Prepared-shingle Roofing. (*A*, Nails.)

shingles, laid 4 inches to the weather, and nailed as the others. The third row follows with one-third-sized shingles and the same spacing, etc. In beginning the fourth row, full-sized shingles are again used and continued as before. The $\frac{1}{2}$-inch space between shingles allows for contraction and expansion and improves the general appearance. If shingles are laid 4 inches to the weather and $4\frac{1}{2}$ inches from the lower ends, all nail heads will be fully covered and protected. Metal should, of course, be used for all flashings and for lining gutters.

Asbestos Shingles.* There are on the market various brands of pressed asbestos shingles mostly cut to a standard size, usually

* Originated in Austria. Patented in the United States in January, 1907.

8 by 16 inches (see Fig. 31, *A*) which are in demand because they are both fireproof and waterproof. They are made of a mixture of asbestos and Portland cement and compressed to any desired thick-

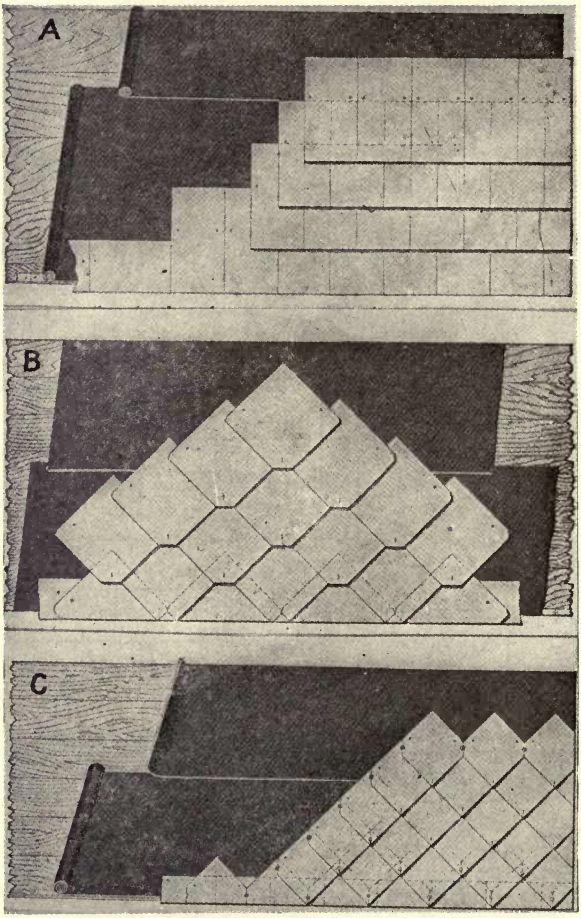


FIG. 31.

A. The American or Straight-laid Method of Applying Shingles.
B. The Honeycomb or Hexagonal Method of Laying Square-cut Shingles.
C. The Diagonal or French Method of Applying Shingles.

ness under hydraulic pressure. When new, they absorb between 5 and 10 per cent by weight of water, depending on the compression they underwent. But when exposed to the air for any length of time, further hydration of the cement decreases their absorptiveness

and increases their impermeability. The strength, durability, impermeability and fireproof properties of asbestos shingles are important factors in overbalancing their high cost. Asbestos shingles like most others are also made in special sizes and forms (see Fig. 31, *B*) and sometimes are applied in the same manner as tile or slate shingles. Sometimes they are laid up in proprietary cements, a common cement for such purpose being a paste made of China wood oil and heavy petroleum residuum.

There are three standard methods for applying shingles which will be described briefly in connection with the application of asbestos shingles, although these methods are equally applicable to other kinds of shingles. These are the American method, the Hexagonal method and the French method. But regardless of the method of application it is absolutely necessary that all asbestos shingles be very hard pressed, only slightly absorbent, reasonably strong, and cut to uniform size and thickness to secure the best results.

American Method of Applying Asbestos Shingles. This method has many modifications of application, but the commonest way is as follows:

The roof boards are laid so as to break joints and nailed securely in place, leaving no loose ends. They should be well-seasoned and preferably of a narrow width. One ply of felt is laid horizontally over the roof boards with a 2-inch lap, and with 6-inch laps on hips and valleys. Furring strips $\frac{1}{4}$ to $\frac{1}{2}$ inch wide are laid under the felt, parallel to and flush with the eaves, and then one course of shingles is laid at eaves lengthwise and parallel to same, overhauling the eaves about $\frac{1}{2}$ inch. The second course of shingles entirely covers the first course (see Fig. 31, *A*), but breaking joints; after which the process is the same as with wooden shingles or slates, exposing not more than 7 inches to the weather and fastening each shingle in place with at least two galvanized iron roofing nails. Nails must never be driven down tight; it is only necessary to drive them firmly. Over the ridges and hips asbestos ridge and hip rolls should be applied with not less than 3-inch laps, fastened in place with ridge roll fasteners. Where the ridge pole does not project high enough above the roof boards to allow direct application of the ridge roll, it is necessary to put in a false pole, so that it is possible to get a direct fastening through the top of the ridge roll (see Fig. 32). All chimneys and valleys must be flashed with copper or other suitable metal.

Hexagonal and French Methods of Applying Asbestos Shingles. The Hexagonal method for applying asbestos shingles is as follows:

The roof is prepared as in the American method. Furring strips

$\frac{1}{4}$ to $\frac{1}{2}$ inch thick by $1\frac{1}{2}$ inches wide are laid underneath the felt parallel to and flush with the eaves. Then one course of asbestos shingles is laid end to end, parallel with and overhanging the eaves, not less than $\frac{1}{2}$ inch; over which is applied one course of shingles entirely covering the starter, breaking all joints (see Fig. 31, *B*). The balance of the roof is covered with shingles, 12 by 12 inches, laid as shown, exposing $9\frac{1}{2}$ by $9\frac{1}{2}$ inches to the weather. All shingles are fastened in place with galvanized nails, but the points of the main body shingles are fastened with copper storm nails. Here also the nails must not be driven down tight, but firmly. All the main body shingles should be laid with the diagonal lines on a 45-degree angle with the eaves. Over the ridges and hips asbestos ridge and hip rolls must be applied in the same way as for the American method. In applying the hexagonal shingles the same method is used as with the rectangular ones of the American method.

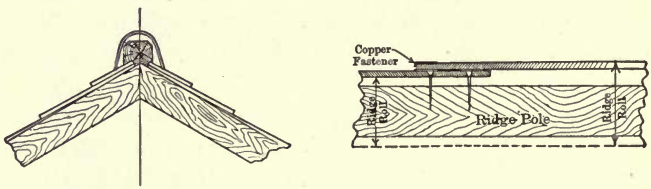


FIG. 32.—Details of Ridge Roll Construction.

The French method is illustrated in Fig. 31, *C*, which is quite self-explanatory.

In general, shingles of all materials when well laid make a handsome and watertight roof, and are easily replaced and repaired. They are serviceable on all but flat roofs, except as noted under slate and tile shingles. The minimum pitch for wooden shingles, slates, tile (when laid as roofing proper) and prepared shingles, is one-third, that is, 1 foot of rise for each 3 feet of span. Table VIII gives the minimum pitch for other roofing materials, but these values may vary somewhat, because each manufacturer usually establishes the incline upon which his own roofing should be applied.

In connection with all shingled roofs, sheet lead is often used for gutters, flashings, etc. The weights recommended for these purposes are as follows:

Gutters.....7 pounds lead per square foot.
Hips and ridges.....6 pounds lead per square foot.
Flashings.....4 to 5 pounds lead per square foot.

Table XXXV gives the thickness and weight of sheet lead. Where sheet lead is to be used to form rather large hips and other important parts of the roof, it is not desirable to lay it in greater lengths than 10 or 12 feet without a joint roll or drip to allow for movement due to the great expansion and contraction of lead from changes of temperature.

TABLE VIII.—MINIMUM PITCH OF ROOFS

	Rise/Span
Asphalt composition	1/24
Tin (standing seam)	1/8
Tin (flat seams)	1/24
Corrugated iron	1/4
Sheet iron	1/4
Copper	1/6
Lead	1/6
Thatch	1/2
Shingles	1/3
Slate	1/3
Tiles, terra-cotta	1/3
Reinforced concrete slabs	1/24
Ready roofing	1/24
Felt, asphalt (or tar), and gravel (or slag) (maximum)	1/4

Tin Roofing

Properties and Application of Tin Roofing. The second type of roofing, that is, tin roofing, is applicable to both flat and pitched roofs, and is adaptable to special and difficult conditions, as well as practicable in every climate. Tin plate (which consists of iron or steel sheeting, tinned with an alloy of lead and tin), copper and zinc sheetings, are the most generally used for this purpose and their predominance is in the order given. The coat on the tin plate is, as noted above, mostly an alloy of lead and tin with the quantity of lead usually predominating. The best grade of tin is that which is coated with an alloy consisting of 30 per cent pure tin and 70 per cent pure lead. The weight of this coating varies between 8 pounds and 40 pounds per box of 112 sheets, 14 by 20 inches, depending on the thickness of the coat. Plates carrying less than 20 pounds should not be used for permanent buildings; for such use 30 to 40-pound coating is most serviceable. Where the coating is all of lead it is called terne plate and this grade is generally used on inex-

pensive roofs. Tin plates usually come in standard sizes, either 14 by 20 inches, or 20 by 28 inches, with prepared edges to enable the roofer to make locked seams between them as they are applied. A modified form of tin-plate roofing consists of rolls of tin plates about 2 feet wide and of various lengths (between 10 and 50 feet) as required. These strips are applied by unrolling, joining and soldering them into a continuous sheet over the entire roof, usually with standing seams. Copper and zinc sheeting also come in standard sizes but are often made in any required size and thickness to suit the particular conditions of the roof.

Tin plates for flat roofs are usually put on with the ordinary flat-lock joint, the sheets of tin being nailed under the lock. After the sheets are nailed and hooked together the hook joints are beaten down with a wooden mallet and then soldered.

When it is desired to make some allowance for contraction and expansion the sheets are fastened with tin clips nailed to the roof as shown at *A*, Fig. 33; in this way there are no nails through the sheets of tin, being held in place by the clips. Fig. 33, *B*, shows a section of this joint.*

To allow for greater ease of movement due to expansion and contraction and to reduce the use of nails and soldering of joints to a minimum, what are known as standing seams are used. These seams are always placed perpendicular to the eaves, but not carried into the gutter, where they would interfere with drainage or cause leaks through water making its way into the seams. Standing-seam roofs are fastened with clips nailed to the sheathing and turned down in the standing seam. Fig. 33 (*C*, *D*, *E*) shows a standing-seam roof in the different stages of construction.

Fig. 33, *F*, shows the joint turned down as a flat lock joint.

In standing-seam roofs or any roof where the tin is laid in long lengths the cross-joints should be double-locked; this is shown at *G*, while the ordinary single lock is shown at *H*.

Tin roofs are sometimes put on in lengths running with the slope of the roof, the strips of tin being turned up and laid between strips of wood, as shown at *J*. This method provides ample allowance for expansion and contraction, and also enhances the appearance of the roof.

Fig. 33, *K*, shows a method used for zinc and copper, while *L* shows how the cross-joints should be made at the ends of the sheet metal; a rise or step is made in the roof and the two sheets of metal turned and locked as shown. In working zinc care must be

* Richey's "The Building Mechanics' Ready Reference."

exercised in making the bends and angles, for if they are made too sharp the metal is liable to crack.

Wherever any metal roof covering finishes at a wall or any place where flashing is necessary the roof metal should be turned up 8 or 10 inches and securely fastened; then this metal should be counter-

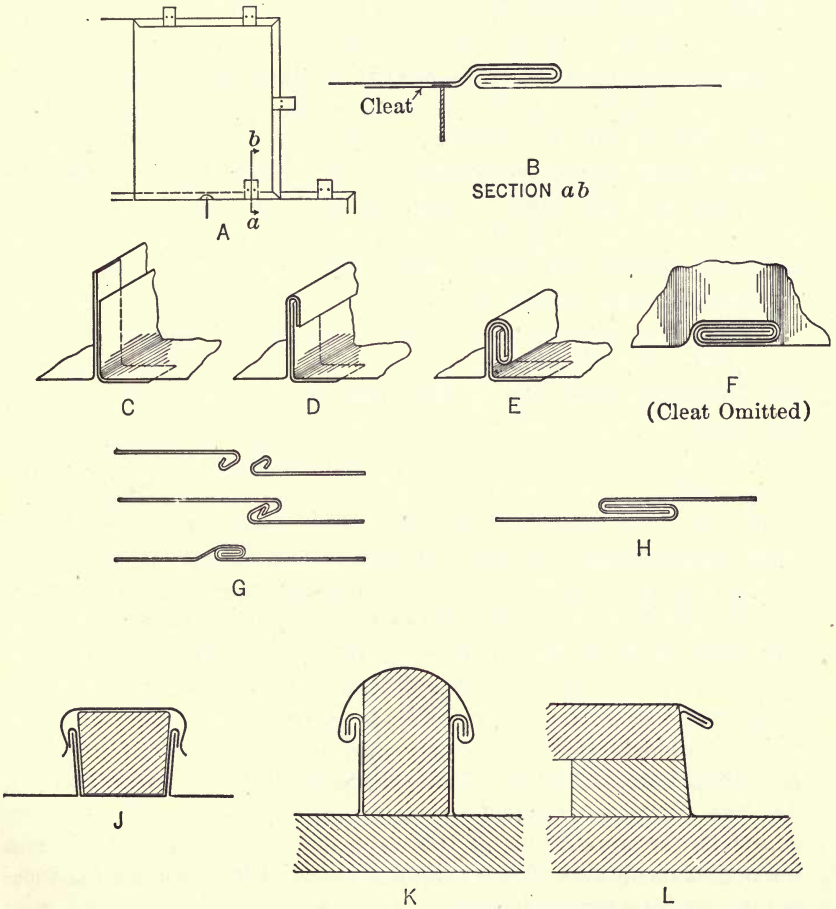


FIG. 33.

flashed and the flashing let into the joint of the wall at least 2 inches and well cemented. This is a part of the work that requires particular attention so as to get everything watertight.

In all metal roofing the main points are to get the joints watertight and to make provision for expansion and contraction.

As soon as the roofing is in place and the joints all soldered, it should then be painted. But just before painting, however, the metal roofing should be gone over and all grease, oil, resin, etc., removed with gasoline or benzene.

Roofs of less than one-fifth pitch are best made with flat seams well locked together. The sheets of tin should preferably be of the small size, 14 by 20 inches, as the small sheets cause more seams and make a stiff roof which prevents buckling. Ordinarily, nails are driven through the edge of the sheet under the lock, but in good work the sheets should be fastened with tin clips or cleats nailed to the roof. This leaves the tin of the roof free to expand and contract. Nails or cleats should be used about every 6 or 7 inches. In soldering the seams rosin, and not acid, should be used, as the latter may attack and destroy the body of the tin, and great care should be exercised and time taken to " sweat " the solder well up into the lock of the seam.

A standing seam should not be used on a roof of less than one-fifth pitch; as, on a flatter roof, while it may be tight for rain, in the winter the snow and ice will cause the water to back up under the seam.

Tin roofing should always be painted on the under side to prevent rusting; a layer of good rosin-sized paper directly on the sheathing is of great benefit, as it absorbs the moisture from the rooms below, and acts as a cushion to the tin.

The metal type of roofing is the most expensive, but is very durable (where a good grade of block tin or copper sheeting is used) and least troublesome if properly cared for; e.g., if a tin roof receives a coat of paint composed of raw linseed oil and iron oxide, once every two years, its life will be prolonged indefinitely. Perhaps the most objectionable feature present in a tin roof is its capacity for absorbing heat, which it retains, often to the great discomfort of dwellers directly underneath such a roof. Most roofers are very expert in the application of this type of roofing, hence it is more important to obtain a good quality of material than to issue exhaustive instructions for applying it.

Felt (or Composition, or Built-up) Roofing

Applying Felt Roofing. The third and most modern method is the Felt or Composition roof. A felt roof generally consists of several plies of treated felt (a product of rag, pulp or asbestos) laid on a properly prepared surface and cemented together with coal-tar

pitch or asphalt and generally (except the asbestos felt roofing) covered with slag, stone screenings or gravel (see Figs. 113 and 114). The felt may be treated with asphalt, oil tar, or coal tar, but the impregnation must be thorough in any case. The slag or gravel must cover the entire roofing surface so as to protect the bituminous coating from direct exposure, and to add weight to the membrane. For approximate weights of various roofings, see Table XXXVI.

The method of applying felt roofings is practically standard; still, roofers and builders may find the following directions helpful. These directions* represent the best practice, but refer only to coal-tar pitch binder and felt. However, any good grade asphalt binder (of the right consistency for the local climate) and felt might be substituted, and equally good results obtained.

First: One thickness of sheathing paper, or unsaturated felt, weighing not less than 5 pounds per 100 square feet, is applied, lapping the sheets at least 1 inch.

Second: Two plies of saturated felt, weighing 14 to 16 pounds per 100 square feet, are applied, lapping each sheet 17 inches over the preceding one, nailing as often as is necessary to hold it in place until the remaining felt is laid.

Third: The entire surface is then uniformly coated with straight-run coal-tar pitch.

Fourth: Three plies of treated felt are laid, lapping each sheet 22 inches over the preceding one, and mopping the pitch the full 22 inches on each sheet, so that in no place shall felt touch felt. Such nailing as is necessary shall be done so that all nails will be covered by not less than two plies of felt.

Fifth: Over the entire surface is spread a uniform coating of pitch, into which, while hot, is embedded not less than 400 pounds of gravel, or 300 pounds of slag to each 100 square feet of surface. The gravel or slag should be from $\frac{1}{4}$ to $\frac{5}{8}$ inch in size, dry and free from dirt.

The sheathing paper, or unsaturated felt, is placed on the bottom next to the roof boards, mainly to keep any pitch which might penetrate the 2-ply felt above it from cementing the roofing to the sheathing boards. It also is of value in preventing the drying out of the roof through open joints from below. The saturated felts should be nailed not only to hold it in place while laying, but where there is any chance of disturbance of the roof from underneath by the wind. The practice in regard to nailing varies in different

* Proceedings of Engineers' Society Western Pennsylvania, October, 1911.

parts of the country, but the fewer nails the better, so long as the roof is held in place.

The two layers of saturated felt first laid are necessary in order to carry and give full value to the amount of pitch which must be handled in one mopping.

For a concrete roof, where the pitch does not exceed 1 inch in 1 foot, nailing is not necessary, and the practice of applying the felt membrane is similar except that a dry sheet is not necessary, the concrete being first coated with pitch and the first two layers mopped the full 17 inches. Special care should always be taken in regard to flashing and to prevent the roofing from being loosened at the edge either by wind or fire. Most leaks occur around flashings and openings.

After the original two layers of saturated felt are used, the additional layers are merely to give additional thickness of wearing material, and with a roof properly laid, the greater the amount of felt and pitch used the greater the life of the roof. Five plies are sufficient for most roofing purposes and when well applied make a very good roof covering.

The coating of gravel, crushed stone or slag helps to hold the coal-tar pitch in place, protects it from wear and from the action of the elements; it also has considerable fire-retarding value. Slag is better than rounded gravel for moderately steep roofs, because besides having sufficient weight it has exceptional bonding power. But if the mineral coating material be too fine its holding power is lessened. If it be too large the stones may cause damage to the roof when it is walked upon and are more apt to roll off. Crushed material with rough, sharp edges has a much better holding power than rounded gravel. Sand or dirt mixed with the gravel is objectionable, as it tends to prevent the gravel from bedding itself in the pitch. Sometimes the sand mixes with the pitch, the resultant being more inert and liable to crack than the clean pitch.

In the final mopping of a felt roof the effect is to get the maximum amount of coal-tar pitch coating which can be kept in place. The flatter the roof the greater the amount of pitch that can be used and the better the pitch and gravel will stay when put in place.

The melting-point of the pitch should be varied to suit climatic conditions. This variation is easily accomplished because it only depends upon the source of the tar, and the point to which the distillation of the coal-tar is carried in the process. But the melting-point of pitch is not definite and in defining it for a particular purpose and locality a specification is advisable. The use of a pitch

with a melting-point too high to allow satisfactory working and requiring the addition of a flux on the work, giving what is known as a " cut-back " pitch, should not be allowed.

The best results are obtained when the slope of the roof is only enough to allow it to thoroughly drain. A method which gives good results on steeper roofs is the addition of some asphalt to the pitch which is used for the top coating. This must be carefully done, as an intimate mixture of the asphalt and coal-tar pitch is not easily obtained. Coal-tar pitch is often prepared for use on moderately steep slopes by the addition of some finely ground inert material, but this is liable to give uncertain results unless the mineral dust is thoroughly and uniformly mixed throughout the mass. Powdered slate and actinolite* are much used for this purpose. Portland cement and plaster of Paris are also used.

In place of felt alone, for building up this membrane-roofing, treated jute or cotton fabric is sometimes alternated between plies. While a stronger membrane results no other advantage accrues to the roofing to counterbalance the increased cost thereof, even when the number of felt plies is reduced thereby.

Where waterproofing and fireproofing are equally important, an asbestos roofing felt is often used. The asbestos, being a mineral, besides being fire-resistant, has the advantage that it will not decay. It is not as absorbent of the preservative though, as felt. This type of roofing is ordinarily applied only by the manufacturer. It usually consists of one or more plies of asbestos felt, with a strengthening material, such as jute or cotton fabric, in the center, and cemented together with asphaltic compounds. Here the reinforcing fabric is essential due to the extreme weakness of the asbestos felt. Roofs composed of this material usually do not need slag or gravel, thereby reducing the weight and presenting a clean, smooth finished surface. The absence of slag or gravel incidentally precludes the possibility of clogging down-spouts and gutters, which seems almost an unavoidable defect of all felt roofs with mineral coverings.

Asbestos felt roofs of the built-up type are applied over boards as follows: First, a composite membrane composed of one untreated asbestos sheet and one treated sheet (usually combined at the factory) is laid on the roof boards, lapping and cementing, and nailing the sheets every 2 inches, with the untreated side down. This is followed with two more sheets of impregnated asbestos felt, placing these succeeding sheets so as to always break joints and

* A calcium-magnesium-iron mineral.

having the next nailing in the center of the sheet thereunder. All nails are on the under edge, protected by the asbestos and binder. Each sheet is mopped its full width.

Asbestos felt roofing over concrete is laid the same way as over boards, except that usually three impregnated sheets are used as described. Sometimes the concrete is first coated with a liquid priming coat, making it possible for the hot bitumen to better stick to the concrete surface.

Varieties of Prepared or Ready Roofings

To reduce cost and labor, and to meet some of the conditions wherein a built-up roof is not satisfactory, innumerable substitutes are made and sold extensively in the form of " ready " or " prepared " roofings. They are of special value for steep roofs and temporary structures. Ready roofings consist mainly of thick, heavy, specially treated rag or pulp and wool felt, covered on one or both sides with rather tough bitumen, leaving a smooth or corrugated finish similar of prepared shingles (see Fig. 34, *A*), and sometimes also surfaced with fine sand or grit (Fig. 34, *B*), or stone screenings (Fig. 34, *C*). The amount of surfacing material that can be used is limited to the amount that can be successfully rolled on the felt. If the particles are too large they may damage the felt in rolling. Ready roofings are also made of one, two, or three plies of thin treated felt, bonded and surface coated with asphalt or coal-tar pitch in the factory, and applied as individual sheets in the field. Coal tar, however, is not considered the best material for a high-grade ready roofing. These and other varieties are made up in rolls of standard widths and weights, of one and two squares, accompanied by the nails and cement necessary to apply them. The standard width is 36 inches, and the standard weights are: 35 pounds for one ply, 45 pounds for two plies, and 55 pounds for three plies. However, there is no uniformity of practice among the different manufacturers. In applying these sheets they are usually laid in the direction of the width of the roof, overlapping from 2 to 6 inches, cemented with a bituminous solution (usually some bitumen dissolved in a volatile oil), and nailed down with the nails not more than 2 inches apart. The best type of nails are made of No. 12 gauge wire, with a cap made of cold-rolled hoop steel welded on in the factory.

Prepared roofings are cheap, easily applied, and quite durable, but as a class, somewhat inferior to a first class built-up roof. The weakest points about ready roofing are the narrow laps and the fact

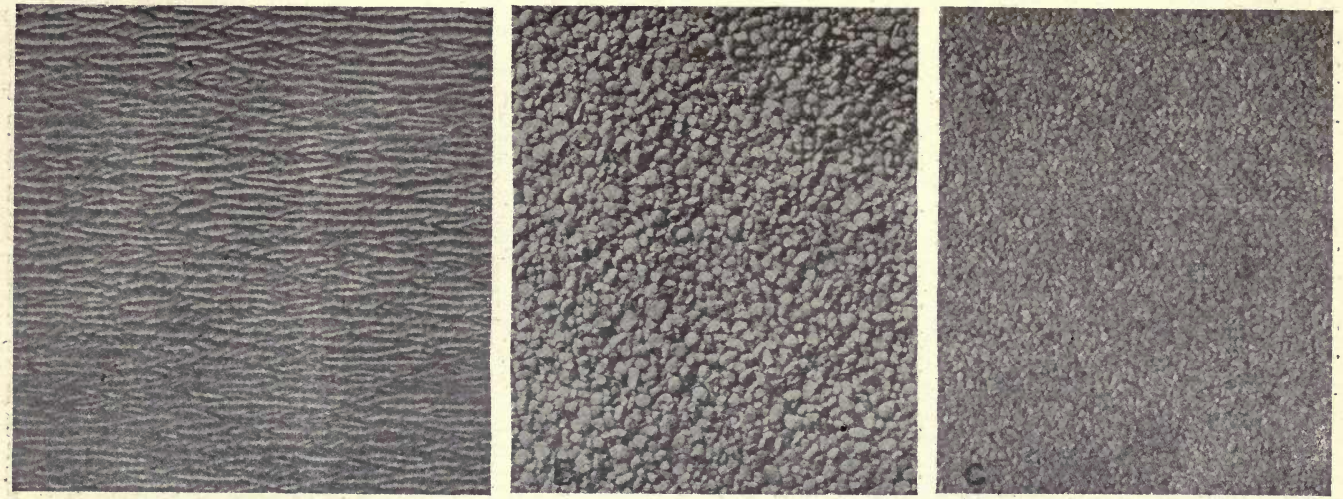


FIG. 34.

A. Rough-surfaced Prepared Shingle. B. Grit-surfaced Prepared Shingle. C. Stone-screening-surfaced Shingle.

that usually a large part of the roof is covered with but one layer of the material, hence a single break will cause a leak.

There are a great many varieties and qualities of ready roofing, the heavier varieties, in general, being more desirable. There are also many methods for holding them down against weather conditions. Fig. 35 shows ready roofing applied to a flat roof, lapped, and nailed down with metal cleats. So or similarly protected, these roofings are equally serviceable for flat and pitched roofs.

Applying Ready Roofings. There are various ways of applying prepared roofing, depending on whether utility or architectural effects are most desirable. To secure the latter effect, the roofing felt should be applied with the pitch of the roof, the joints and roofing nails being covered with a molded batten of wood, about $\frac{7}{8}$ inch by $1\frac{1}{2}$ inches. The under side of this batten should be rabbeted to a depth of $\frac{1}{8}$ inch to make room for the heads of the roofing nails. The rabbet should be filled with a plastic cement, such as accompanies the roofing, and the latter then securely nailed. Roofs so prepared have the appearance of a standing-seam tin roof. The most common method of applying ready roofings, however, is as follows:

A good foundation for the roofing is very important. Hence the practice advised for applying sheathing boards in connection with shingle roofs is directly applicable here. Also in the case of cracks or knot holes, in the boards it is good practice to tack pieces of tin over them. If the weather is warm, the ready roofing should be unrolled and allowed to lie exposed to the sun and air to thoroughly flatten out, and stretched before being nailed down, otherwise it may wrinkle or buckle. If the weather is cold, the roofing should be kept in a warm room just before it is unrolled and used, taking special care to stretch it out thoroughly and nailing it in place while still warm. Sheets should not be cut when spread on top of those already laid, nor should the roofing be torn, but always cut with a sharp knife to insure straight edges. For very steep roofs it is often better to cut the desired lengths on the floor. It is very important to plan the work in advance as far as possible, particularly at flashings, around vertical walls, chimneys or any other projections from the roof and at laps or joints.

The roofing material should always be laid so as to have the seams or laps run parallel with the sheathing boards, as this arrangement will insure a uniform and even nailing surface for securing it. Great care is required to see that the roofing laps over solid sheathing boards, and not over a joint or crack. If a lap, on account of the position of a previous sheet, should occur so as to bring the nailing

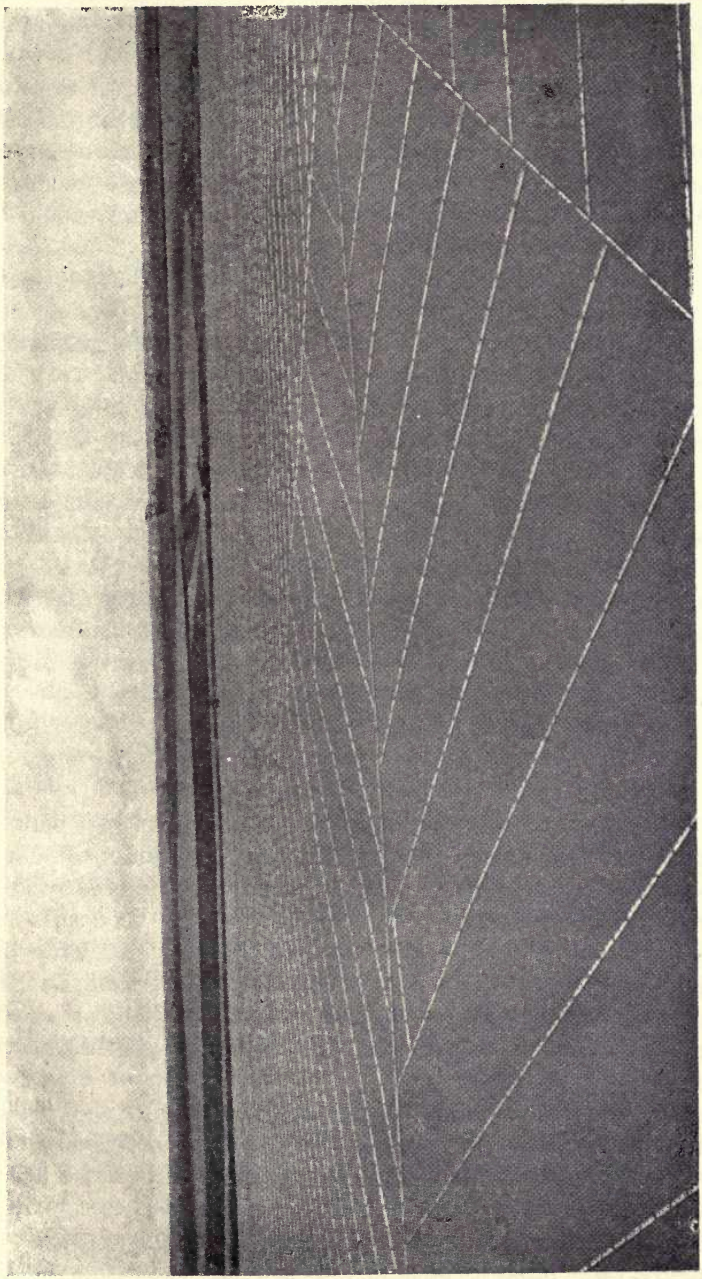


FIG. 35.—Prepared Roofing Held Down with Galvanized-metal Cleats Nailed over Laps.

points directly over a joint or a crack in the sheathing boards, the next sheet should be shifted an inch or two so as to avoid the crack.

Upon a flat roof the sheets are laid with the slope of the roof when the sheathing boards run that way. Beginning at the left, the first sheet is unrolled and placed so as to permit about 3 inches to extend up against the fire wall, or in the event that the roofing is turned over sheathing boards at the side, 1 or 2 inches should be allowed for this purpose, and from $1\frac{1}{2}$ to 2 inches at the eaves or end of the sheet. This sheet must be carefully adjusted and flattened into position, folding the sheet carefully where it projects against the fire wall so as to make a good corner without breaking the felt. It is temporarily secured in place by driving a few nails along its edge and end; then the next sheet is unrolled, allowing it to overlap at least 2 inches, being careful to obtain a uniform lap along the entire seam. After this second sheet is carefully adjusted and flattened out, it should be nailed directly over the 2-inch lap, placing the nails within $\frac{1}{8}$ inch of its edge. This is repeated until the entire roof is covered.

Making watertight flashings against fire walls, is equally as important as making watertight joints between plies and laps in the various roofing materials. This is discussed in the following article.

Roof Flashings

An important part of the construction of roofs and roof parapet walls on large brick or concrete buildings is the flashing. Flashing may be defined as a piece of metal or waterproof material used to keep water from penetrating the joints principally between a fire wall or projection through the roof of a building or other structure. Its efficient location and application as well as the selection of the best material are matters that require careful study. For general work most roofers can supply and apply flashings meeting all requirements.

The vital part of a brick parapet wall is the inner side, which heretofore was made up of common brick laid up in ordinary lime mortar. As a result, and owing to the freezing of the brick above the roof flashing—due to saturation from snow or rain—many brick parapet walls, after a few years became a crumbling mass. In consequence the flashing became loosened and water percolated through the joints to the detriment of the interior. To avoid the

above condition it is now the practice to build the inner side of the brick parapets of hard burned vitrified brick laid up in cement mortar and covering the top with a waterproof coping. In addition to this the roofing material is sometimes carried up to the under side of the coping. But a common procedure is to take one or more strips of felt or ready roofing about 12 inches wide, folded in the center and fitted into angles at fire walls, chimneys, etc., so that 6 inches project up these surfaces and 6 inches lap over the roofing. These strips are fastened (if more than one is used as on composition roofs) with a row of nails at the upper edge of the upper strip by driving them into the mortar joints between the bricks, and securing the lower edges (if ready roofing is being applied) with a row of nails applied similar to an ordinary lap, or by mopping with pitch or asphalt (if composition roofing is applied) and completely coating the surface of the flashing strip as is ordinarily done on the roofing proper. All flashings on brick walls, etc., should be counter flashed with metal so as to prevent water from eventually working in behind them. These counter flashings must be thoroughly secured in a mortar joint above the roof flashings and turned down over the seam for at least 4 inches. For buildings subjected to gases and fumes, saturated felt properly coated with good asphalt or pitch preparations will give good results. For buildings located outside of industrial centers, non-corrosive metal flashings give very good results. A very efficient means of fastening both the flashing and counter flashing is shown in detail (applicable both for composition and ready roofing at parapets) in Fig. 36. This detail, recommended as good practice by the American Railway Engineering Association,* makes use of a 2- by 4-inch timber with one edge beveled, laid continuous in the parapet at the proper height in place of a stretcher course of brick. This serves as a nailing strip for a light wooden strip holding the flashing and counter flashing in place. After placing the flashing the slot is completely sealed up with cement grout or roofing cement.

For the proper flashing of concrete parapet walls the detail shown in Fig. 36 can be recommended.* A 2- by 4-inch piece of lumber is ripped on the diagonal as shown and then placed in the forms at the desired height, the upper strip being securely nailed thereto, so as to insure its removal when forms are taken down, while the lower piece is just tacked to forms (from outside) with wires or nails driven into it as shown to anchor it to the concrete. The flashing and counter flashing are then placed in the same manner as for brick walls.

* Concrete Vol. 9, No. 6, December, 1916, p. 197.

An ingenious and inexpensive flashing is shown in Fig. 37. The metal lock referred to in the diagram is of galvanized sheet iron, and acts as the backbone for the flashing, which may be made of ordinary felt or strips of prepared-roofing felt, these often being substituted for the more expensive all-metal flashings.

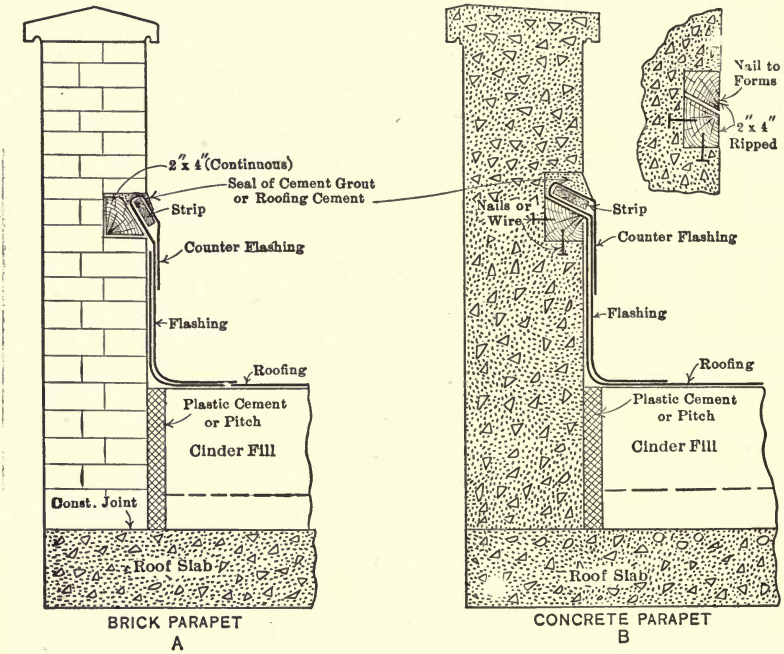


Fig. 36.—Flashing Details.

Roof Cutters

The function of impervious roofing is to shed the rainwater so that none finds entrance into the building. On small and unimportant structures, rainwater is allowed to drip off the eaves, often discoloring the walls. On most structures, however, both large and small, provision is made for taking care of the drip by providing gutters directly under the eaves, or other roof plane, and in the valleys of the roof. The most modern practice is to slope the roofs of buildings so as to provide drainage in the direction of the center of the structure, where the gutters and conductors are arranged for easy access. This arrangement avoids marring the architectural effect of the facade. Fig. 38 shows typical arrangements of metal gutters and conductors, for mill and factory buildings.

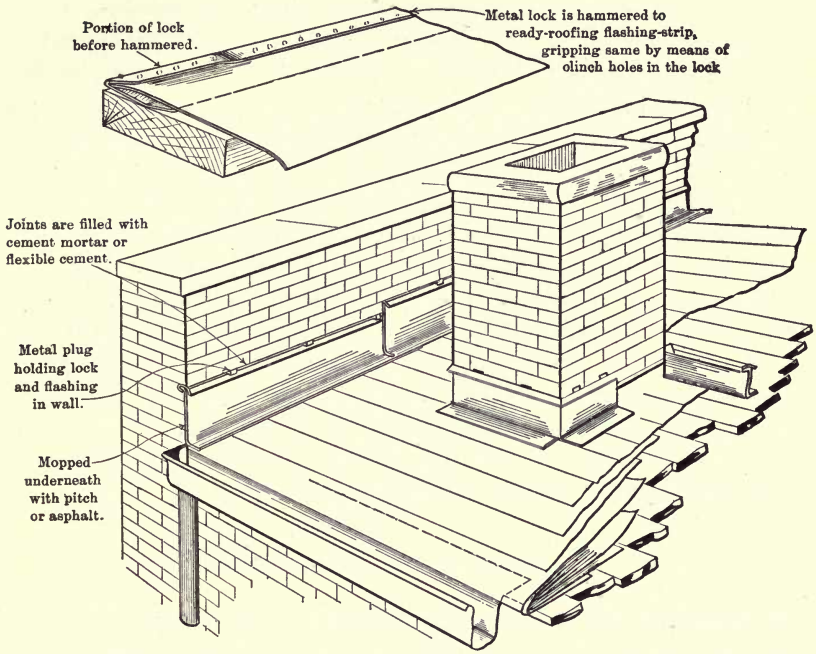


FIG. 37.—Showing Method of Using Felt in Place of Metal Flashings. (Metal Lock Illustrated is Patented.)

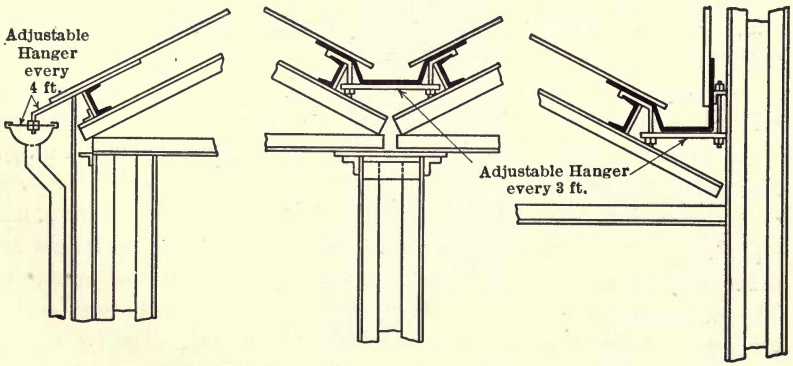


FIG. 38.—Eave and Valley Gutters of Galvanized Iron or Steel. (American Bridge Co.'s Standards.)

Gutters should be sloped not less than 1 inch in 15 feet, and if made of sheet iron, or steel, should preferably be galvanized than tinned because the latter variety corrodes more easily around an abrasion or other slight damage. The gutters and leaders, or conductors, made of these metals should be of No. 22 to 20 gauge (18 to 22 ounces per square foot). On the better class of structures, gutters and conductors are usually made of copper, in which case the metal used varies in weight, from 14 to 20 ounces per square foot. Hanging gutters are frequently made of considerable length; therefore they should be strongly built, as otherwise they are liable to deflect from a uniform grade. Simple and inexpensive gutters are often made by fastening a strip of wood, of appropriate size, close to the end of the eave of the roof and sloping towards the conductor. This strip runs along the entire length of the eave, and is covered by the material used for the roofing, or by sheet metal. This practice, however, is mainly resorted to on low buildings, such as mill buildings and small-town railroad stations.

Functional Roofings

Definition, Use and Varieties of Functional Roofings. Functional roofings consist of such materials as both waterproof and roof the uppermost part of a structure; that is, they are compositive and include all those not covered by the previous types of roofings. Most of the functional roofings are of recent origin and have a limited use because they are usually adapted to special types or temporary structures. They are for the most part though, efficient and often inexpensive. The following are examples of functional roofings:

Corrugated or crimped galvanized sheet iron (see Fig. 39) and asbestos-covered corrugated sheet iron (see Fig. 40). These are often used for the roofs of freight cars and small mill buildings; also metal shingles, which have a limited use on railroad structures. In general, however, steel or impure iron materials are avoided, especially on important structures, even though these materials are protected, because of the necessity of frequent repair or renewals. The structural-composite roofing shown in Fig. 41 is serviceable for train sheds, depots, and large mill buildings. Heavy cotton canvas, sometimes treated with a preservative, but always painted, is extensively used as roofing for freight and passenger railroad cars and on decks of ferry boats. Glass roofings, for which there are many methods of making watertight joints (two of which are

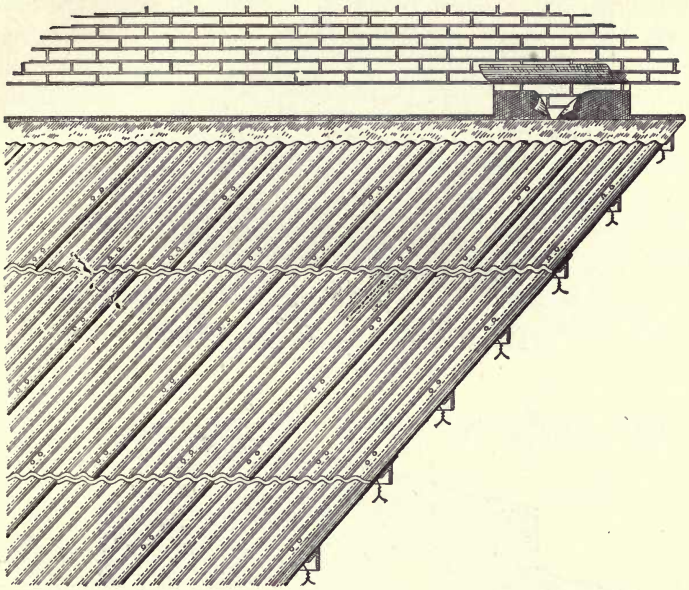


FIG. 39.—Corrugated Galvanized-iron Roofing, Showing Method of Lapping and Flashing.

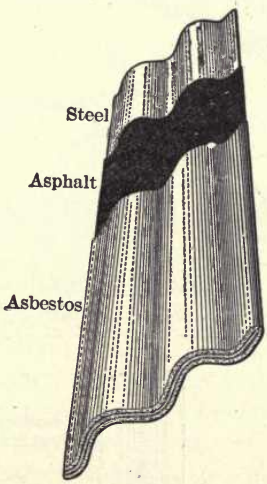


FIG. 40.—Asbestos-covered Corrugated Roofing.

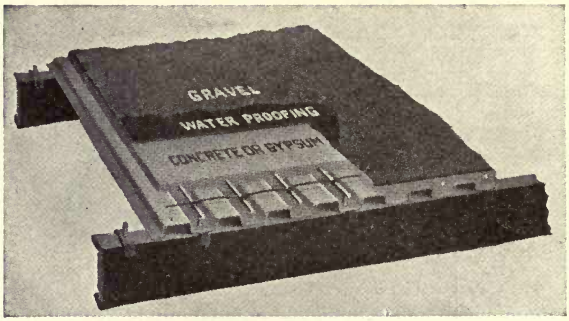


FIG. 41.—Structural-composite Roofing.

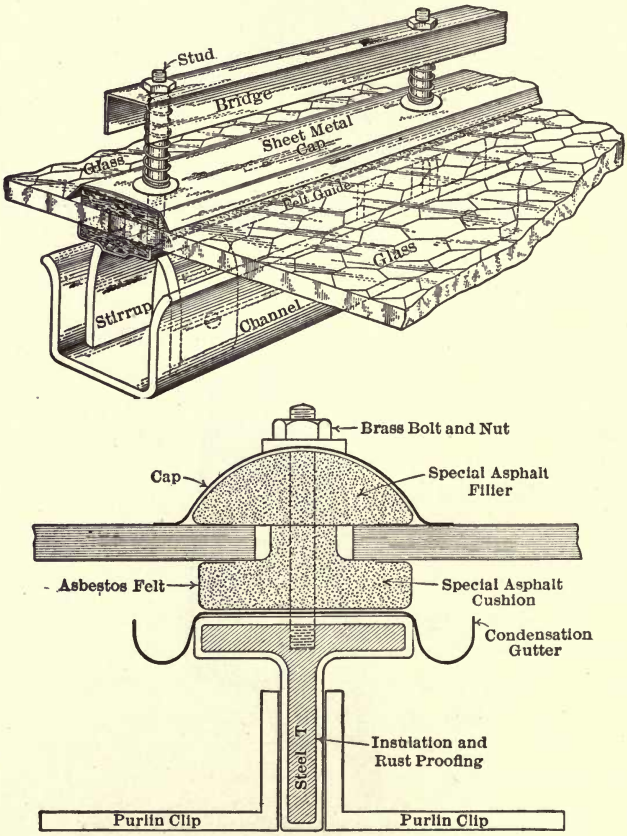


FIG. 42.—Two Types of Watertight Joints in Puttyless Glass Roofing. (Patented.)

shown in Fig. 42) are well-adapted for depots and general skylights of buildings; also for roofs of buildings used in the production of motion pictures. Roofs of many factory buildings and all concrete buildings are made either of reinforced concrete or, to insure better watertightness, have an integral waterproofing compound added to the concrete.

The method of applying functional roofings depends on the material and also somewhat on the structure. Sheet and corrugated galvanized iron are usually nailed down to the purlins and lapped both lengthwise and crosswise as shown in Fig. 43, *A*. Sometimes

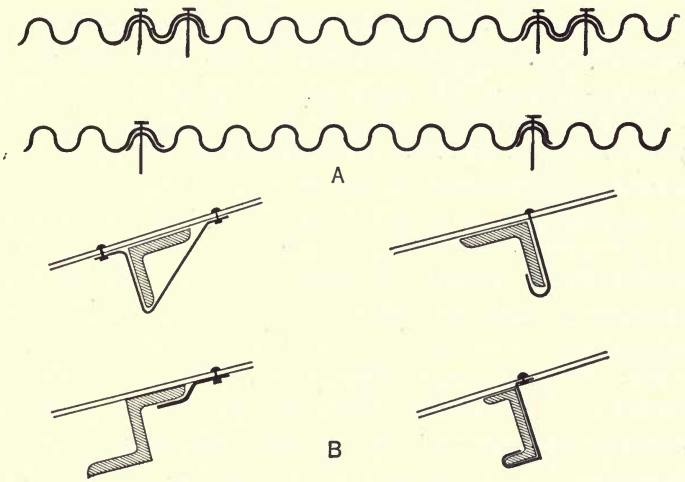


FIG. 43.

A. Methods of Nailing Down Corrugated Sheet Iron on Roofs and Sidings.
B. Methods of Applying Sheet or Corrugated Roofing to Roof Framework.

small iron cleats are riveted to the sheets which hook on to angle irons screwed on to the purlins or roof frame work. Fig. 43, *B*, shows several methods in common use. The former method produces a more durable and watertight roof.

The slab type of functional roofing is usually made so as to lap over each other and fit into prepared grooves. The joints are usually made watertight with an adhesive, elastic compound.

A roof built of concrete blocks or blocks of any other material will not of itself be watertight because of the many joints; such roofs must first be waterproofed usually with a membranous roofing material, hence these materials cannot be classed as functional roofings.

CHAPTER IV

WATERPROOFING EXPANSION JOINTS IN MASONRY

Function and Properties of Expansion Joints. Expansion joints constitute one of the basic causes contributing to the difficulty of making masonry structures watertight. When masonry is to be waterproofed its expansion joints must be so made that water cannot pass through them. This is usually accomplished either by some form of tongue and groove, by a bent cutoff plate, by gaskets, and so forth, in endless variety. Designers usually include some form of bitumen or other sticky, plastic material as a joint filler.

To devise a joint that will remain tight under all conditions of weather and stress is exceedingly difficult. Most failures of waterproofing are due to the lack of joints, to joints not placed where the tensile stress is large, to narrow joints, or to joints which do not remain watertight. In a great many cases if an adequate number of good watertight joints were provided no other waterproofing would be required. Concrete and other masonry can nearly always be made as impervious as necessary between cracks, and therefore the waterproofing of a structure is often a question of waterproofing its joints. Hence, we shall investigate, (1) the methods used for the proper provision for expansion and contraction in concrete or other masonry; and (2) the methods used for proper waterproofing of the joints.

Expansion joints are used in structures to allow the masonry to expand and contract freely with changing temperature, and to permit other necessary, small, internal movements and readjustments. Expansion joints are, in fact, simply cracks built into the masonry to anticipate or take the place of the internal cracks and breaks. A sufficient number of these joints must be provided to avoid disfiguring the masonry with unsightly cracks (see Fig. 124). The following instance demonstrates the commonest way that cracks occur in masonry. Structural materials have a varying coefficient of expansion* (see Table XXX).

* The coefficient of expansion for any material is the factor which expresses the change per unit of length for each degree of temperature.

The coefficient of expansion for concrete is variously assumed as .0000055 or .0000065 per deg. Fahr. (about $\frac{1}{8}$ inch in 100 feet for each 15 deg. Fahr.). These coefficients vary somewhat with different proportions and kinds of aggregate in the concrete. Assuming for concrete a modulus of elasticity of 2,000,000 pounds per square inch and an ultimate tensile strength of 200 pounds per square inch, a distortion, in tension, of 0.0001 inch will fracture it.* Fifteen degrees Fahr. drop in temperature produces this change in length and is thus just sufficient to break restrained concrete.

Monolithic Construction Obviates Expansion Joints. To avoid the use of expansion joints, small structures are often built as monoliths for which the waterproofing is fairly simple. Larger structures can be built monolithic by imbedding sufficient steel in the concrete so that the concrete is not stressed beyond its breaking strength.

The elimination of joints by this method may be carried a step further. Reinforcing metal can be placed the whole length of a structure of any size or of a structure whose ends are restrained. But in this case the function of the steel is quite different from ordinary reinforcing steel. Fifteen degrees drop in temperature will break the concrete as if the steel was not present. But the introduction of the steel merely causes the cracks to be smaller and closer together. Steel has about the same coefficient of expansion as concrete. But the ratio of ultimate tensile strength to modulus of elasticity is so much greater with steel than with concrete that, while concrete is broken by a 15 deg. Fahr. drop in temperature, a drop of 100 degrees only stresses steel to its safe working stress, a drop of 175 degrees to its yield point, and no temperature change whatever is able to break it. A moderate amount of steel makes the cracks so small and close together that they are unnoticeable. The actual quantity of steel, which can be readily computed, varies between .1 per cent and .3 per cent of the cross-sectional area of the concrete depending on climate and local conditions, as, for instance, whether the structure is above or below ground. None the less it must be borne in mind that the concrete is fractured and that therefore water will find its way through, particularly if under a head. The total cross-section of the cracks will be about the same in both cases, but the capillary and fluid friction through the mass will considerably reduce the permeability of the concrete, and eventually these minute cracks may be closed up with silt, thus making the structure completely watertight.

* Modulus of elasticity equals stress divided by deformation; using these values the deformation is 0.0001.

Design and Spacing of Expansion Joints. The width of a joint controls the longitudinal movement of each section, and, hence, controls the movement of the entire structure. Therefore expansion joints should be large enough to accommodate any movement that may occur and spaced sufficiently close together to eliminate all other cracks or joints. In other words, the joints must be so spaced that under all conditions of temperature change, loading, vibration, or foundation settlement, the masonry between the joints will be a single monolith. The proper location and design of these joints require forethought, experience and good judgment.

To design a joint, the change in length is computed for the temperature variation of the particular climate. This is increased as needed to allow for other movements, plus a small amount as a factor of safety. The spacing of the joints is determined by computing the frictional resistance to movement between the masonry surfaces. The joints must be so close together that the stress resulting from this friction is within the safe tensile strength of the masonry. Stresses due to other causes must of course be computed and combined with the friction stress.

Joints may be located at intervals of from 25 to 50 feet, although under favorable conditions and sufficient reinforcement, larger sections may be used. But the larger the section between joints, the wider should the joint be made. For restrained structures and large gravity retaining walls, the maximum distance that joints should be spaced is 50 feet. Concrete walls which are less than 3 or 4 feet in thickness, and subject to about 60 deg. Fahr. seasonal change of temperature, should have joints spaced about 30 feet apart.

Joints in Brick Masonry. Expansion joints in brick masonry are rarely employed, but the joints between the bricks require careful attention where impervious walls are necessary, as for instance, in residences.

The mortar in the joints of brick masonry is usually deficient in density and hence is quite absorbent and more or less permeable. Often for the sake of enhancing the appearance of a residence the mortar is raked out of the joints for a depth varying between $\frac{1}{2}$ and 1 inch and left so. This is poor practice because very little mortar may remain near the front face of the brick to prevent the percolation of water especially when aided by a driving rain. This often happens, resulting in damp and wet interiors. Where it is proposed to use this type of joint in the masonry, then, to make these joints impervious, half the raked-out space should be filled with a pointing mortar. The pointing material may be either neat cement or mortar

composed of Portland cement and sand in equal proportions, mixed with enough water to form a stiff paste. This paste should be tamped in with a metal calking tool and the joint facings can then be finished according to one of the pointings shown in Fig. 44.

Where this practice is not resorted to, i.e., where neither raking nor special joint mortar are employed, and where dry and dampproof interiors are desired (assuming that the best grade of bricks were used) then the mortar joint proper, made as the work progressed, should also be pointed as illustrated.

The Slip-tongue and Plane-of-weak-bond Joints. The types of expansion joints used in practice are almost as varied as the types of masonry structures built nowadays. The simplest expansion joint for concrete dams, walls, etc., is a plane of weak bond in the structure,

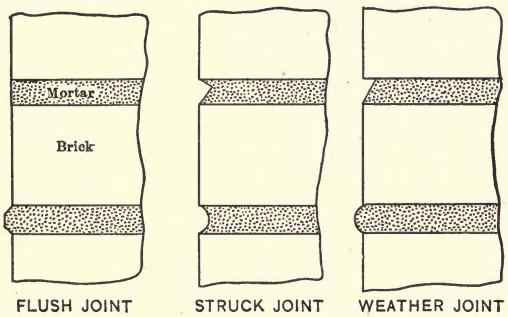


FIG. 44.—Types of Mortar Joints Used for Appearance and Utility.

made by building one section first and coating it with bitumen or other compound, or nailing to it one or more plies of treated felt, sometimes bonded with bitumen, against which the concrete of the second section is poured.

That it is necessary to create a plane of weak bond in the structure, by interposing some form of coating or sheeting between the joints of all sections, is evident from the fact that the separation at the joints is not otherwise uniformly perfect. When joints are formed without interposing any sheetings or other separating material, then by pouring one section after the adjoining section has set, no adhesion of any large amount would be expected under these conditions; yet it often happens that there is a strong enough bond to break through solid concrete alongside the joint. This is evidenced by the many meandering cracks (other than shrinkage cracks) often seen close to and paralleling the V-groove formed in the face of concrete walls at joints.

Another phase of the joint problem worth noting is the protection of horizontal joints. In the construction of concrete walls, abutments, etc., almost sole attention is given to vertical expansion joints and their protection against the seepage of water through them. Little if any real attention is paid to horizontal joints, and yet it is these joints that are mostly responsible for discoloration (see Fig. 2) and equally responsible for leakage in these and other structures. Whether the horizontal joint be a days-work joint or a construction joint, its existence is a source of danger to the unity of the structure from the waterproofing point of view, and should be cared for as effectively as vertical joints. Fig. 45 shows an effective

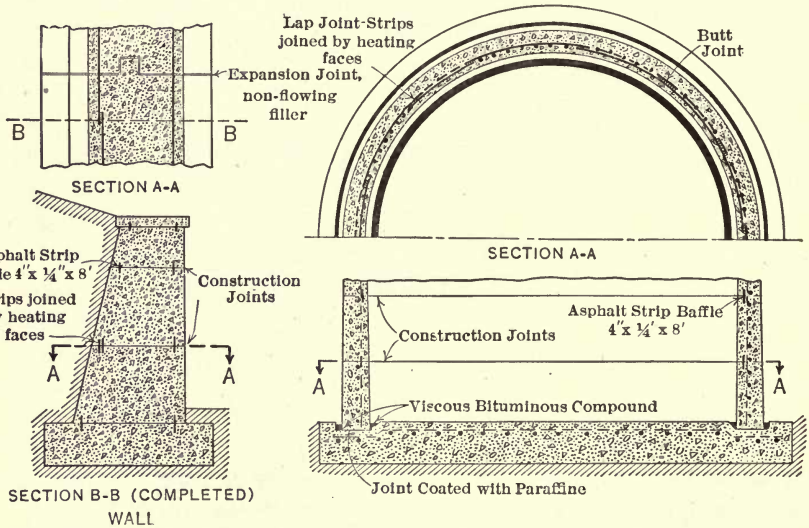


FIG. 45.—Location of Horizontal Baffle Joints in Walls and Tanks.

method of waterproofing horizontal joints. Its efficiency is sometimes doubtful because the slip tongue, which is generally made of sheet iron, and though sometimes painted with a preserving compound, too often corrodes and vitiates its function. What should be used as a slip tongue to avoid such defects is a non-corrosive material and such may be made of tough elastic asphalt strips similar to the precast expansion joint fillers used in concrete road construction. Fig. 48 shows such a scheme of protecting horizontal joints in which the barrier is placed on the finished concrete in the form of a strip, before the new concrete is deposited.

Illustrations of Expansion Joints. One requisite for all forms of expansion joints is that they be so constructed as to retain the

joint filler (which alone waterproofs the joints) as long as the structure lasts. A second requisite is that the joint filler itself retain its properties, and last equally as long, or allow of replacement at definite intervals. The first requisite will be well provided for by adhering to the basic type of joints shown in Fig. 46, modified, of course, to conform to any special requirement. The second requisite will be satisfied by any material which does not lose its "body" or substantial character, adhesiveness and elasticity, at least not rapidly, and is not affected by water. Such compounds are discussed further on in this chapter.

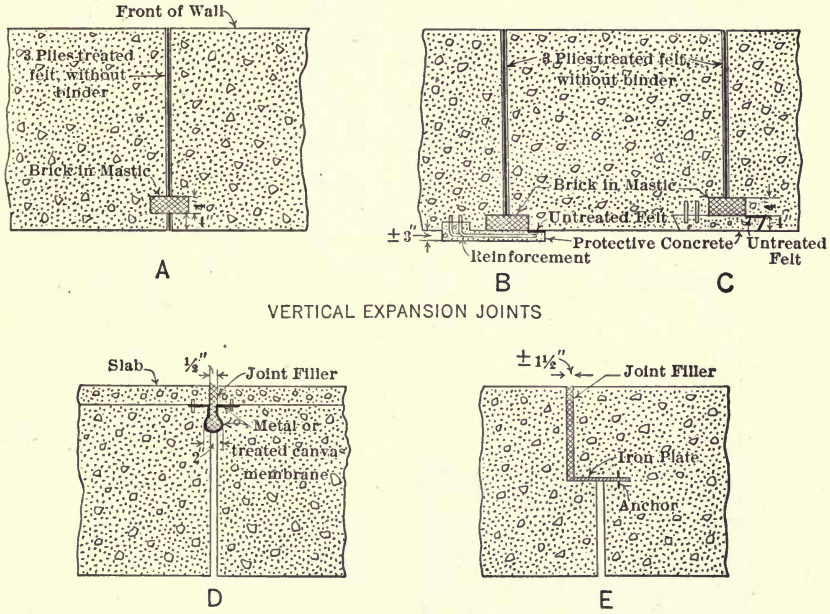


FIG. 46.—Basic Types of Waterproofed Expansion Joints.

Fig. 47 (*A*, *B*, *C* and *D*) is taken from a report by the Committee on Buildings and Structures of the American Electrical Railway Engineers Association. These joints have several interesting features which are evident and self-explanatory.

Fig. 48 illustrates a method of waterproofing horizontal and vertical joints in concrete walls; the former by means of gaskets or strips of fabric thickly coated with a bituminous material; the latter by means of rolls of the same material fitted in a prepared groove of one section and surrounded by the concrete as poured for the next

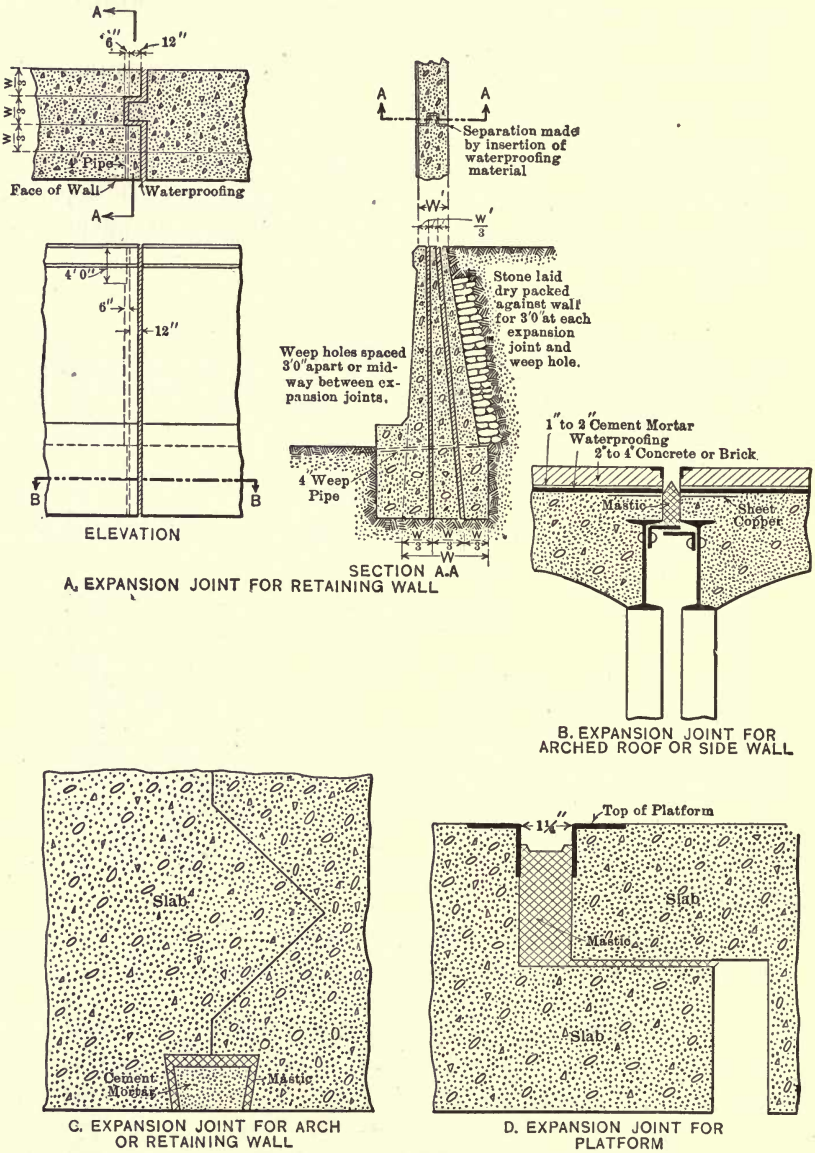


FIG. 47.—Typical Forms of Waterproofed Expansion Joints Used for Various Structures.

section, with the rest of the joint between sections filled with several plies of treated felt. It is possible to make very efficient expansion joints in this manner, provided the compound used for treating the fabric, of which the gaskets and rolls are made, remains tacky and

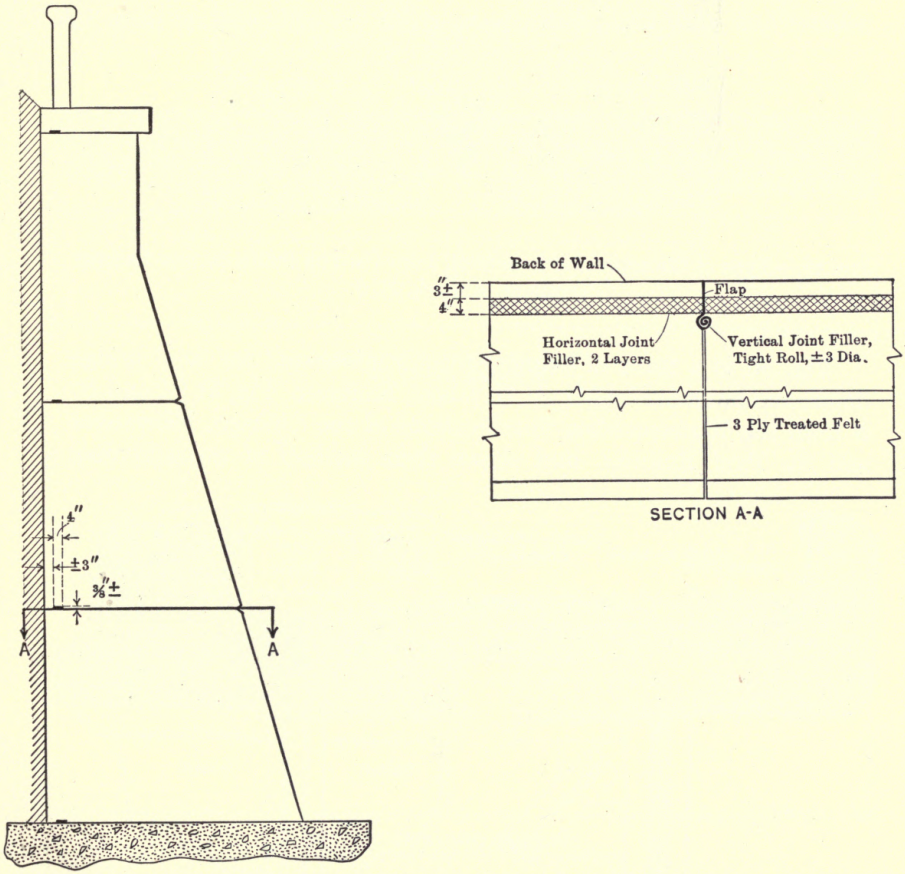


FIG. 48.—Horizontal Waterproof Baffle, and Vertical Expansion Joint and Joint Filler Used on Concrete Retaining Wall of the Brighton Beach Line, B.R.T. Railroad System, Brooklyn, New York.

adheres to the concrete when set, and elastic, so that it "gives" when contraction and expansion take place.

Fig. 49 shows a horizontal joint for a concrete floor. This joint is waterproofed by means of a copper V-joint anchored and filled with a joint roll, consisting of treated fabric wound tightly on itself and covered with some tenacious and elastic compound, which when

the joint contracts, forms a bulb upward, and on expansion forms a groove. But this operation is only possible when the joint filler adheres tenaciously to the sides of the joint.

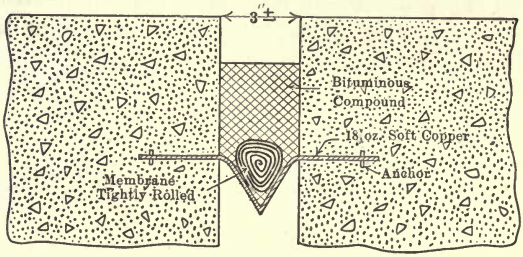


FIG. 49.—Type of Waterproofed Expansion Joint Used on Public Service Railway Terminal, Newark, N. J.

Fig. 50 is a form of expansion joint advocated for solid bridge floors, and patented by Mr. A. H. Rhett, Engineer. Fig. 51 (*A* and *B*) is from the Waterproofing Specifications of the Chicago, Milwaukee and St. Paul Railway, and shows their method of waterproofing

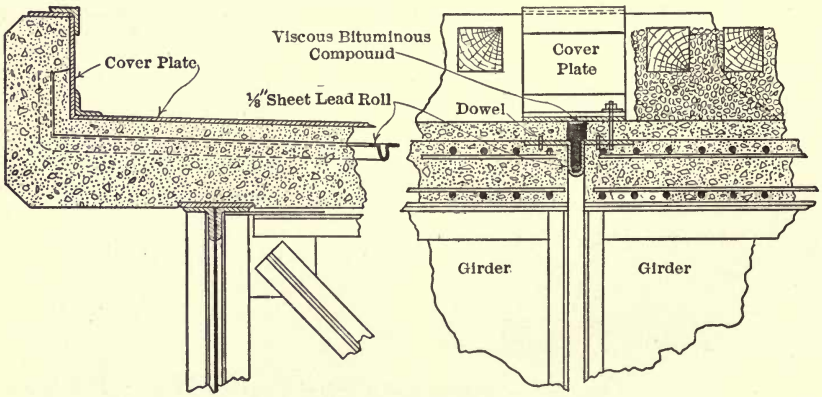


FIG. 50.—Waterproofed Expansion Joint for Solid Floor Bridge. (Patented.)

bridge floor expansion joints. This method consists in applying two continuous strips of treated felt, 36 inches wide, over the expansion joints, being careful to see that no bitumen gets between or under the two strips of treated felt. Then the top strip is mopped with hot bitumen and the waterproofing proper carried over the top of the felt as if no joint existed.

The joint shown in Fig. 52, *A*, is a vertical square or rectangular recess filled with plastic clay. The clay must be of the best quality, placed while wet and rammed absolutely solid into place, otherwise it will not cohere into a unit mass. Fig. 52, *B*, shows the rectangular and triangular tongue-and-groove types of joints commonly used for small masonry bridges and abutments, parapet walls and retain-

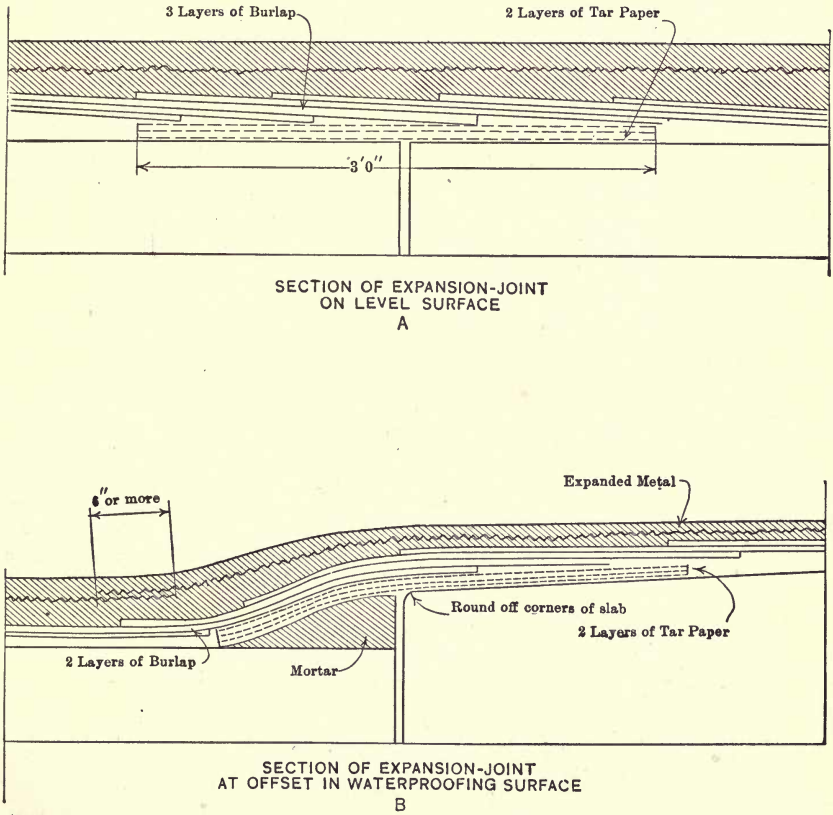


FIG. 51.—"Unfilled" Type of Waterproofed Expansion Joint.

ing walls. They form merely a weak bond in the structure, but permit lateral movement and so prevent disalignment. However, unless some barrier, as a bituminous sheet or membrane, is interposed, water will readily seep through these joints.

Fig. 53 shows a reinforced tongue-and-groove joint successfully used on the Compton Hill Reservoir, St. Louis, Missouri.* The

* Engineering News, December 23, 1915, Vol. 74.

joint was filled with treated felt and pitch binder as each section was built up. Fig. 54 shows an all-adaptable form of joint waterproofed with a soft asphalt contained in a copper bulb the imbedded portion of which is perforated so as to bond more securely. Fig. 123 is an efficient form of joint used by the Delaware, Lackawanna & Western R. R. on two of its viaducts.

Cutoffs in Expansion Joints. Water should not be allowed to enter expansion joints; but if this be inevitable, then it is best to use some form of cutoff, near one face of the structure, and to provide proper drainage within the structure. Copper, tin, galvanized iron, lead and zinc sheeting are often used as cutoffs in expansion joints,

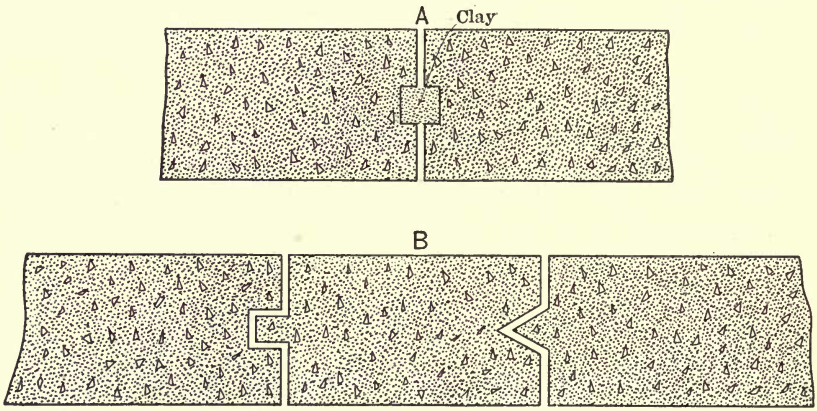


FIG. 52.

A. Rectangular Recess in Expansion Joint, Filled with Plastic Clay.
B. Rectangular and Triangular Tongue-and-groove Expansion Joints.

and all serve their purpose very well, but the copper sheeting best of all. There are two types of cutoffs, known as the internal and external. One of the best illustrations of modern practice showing the use of the internal type of cutoff is in the expansion joints of the Kensico Dam on the Catskill Aqueduct of New York City.

The expansion joints in this dam contain a strip of copper placed across each joint near the upstream face to cut off leakage (see Fig. 55, *B*). This cutoff was constructed in the following manner: A portion of the strip was placed in a groove in the vertical face of the masonry forming one side of the expansion joint, and surrounded with concrete or mortar, allowing the remainder of the strip to project, as shown in detail in Fig. 55, *A*.

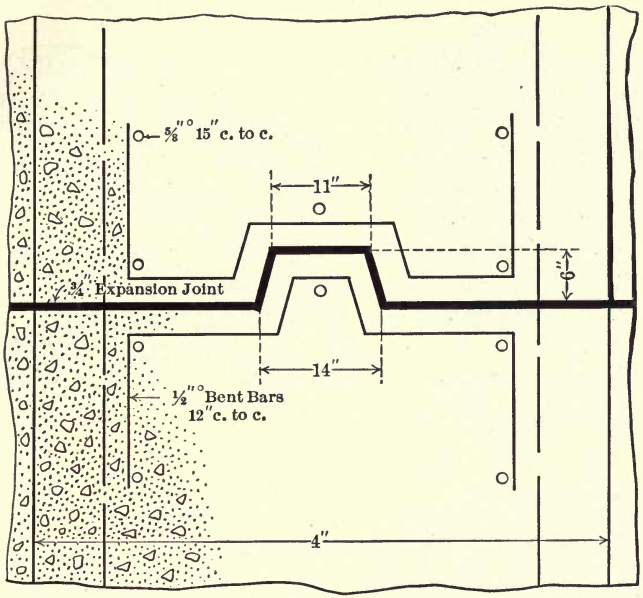


FIG. 53.—Detail of Reinforced Expansion Joint for Retaining Walls.

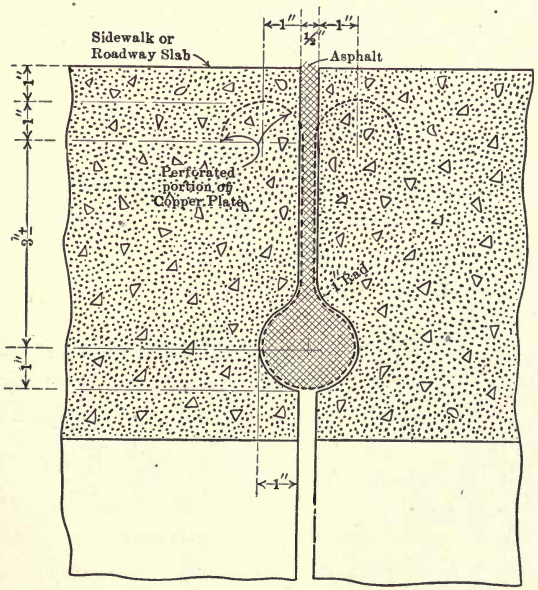


FIG. 54.—Type of Waterproofed Expansion Joint Used on the Brooklyn-Erighton Viaduct, Cleveland, Ohio.

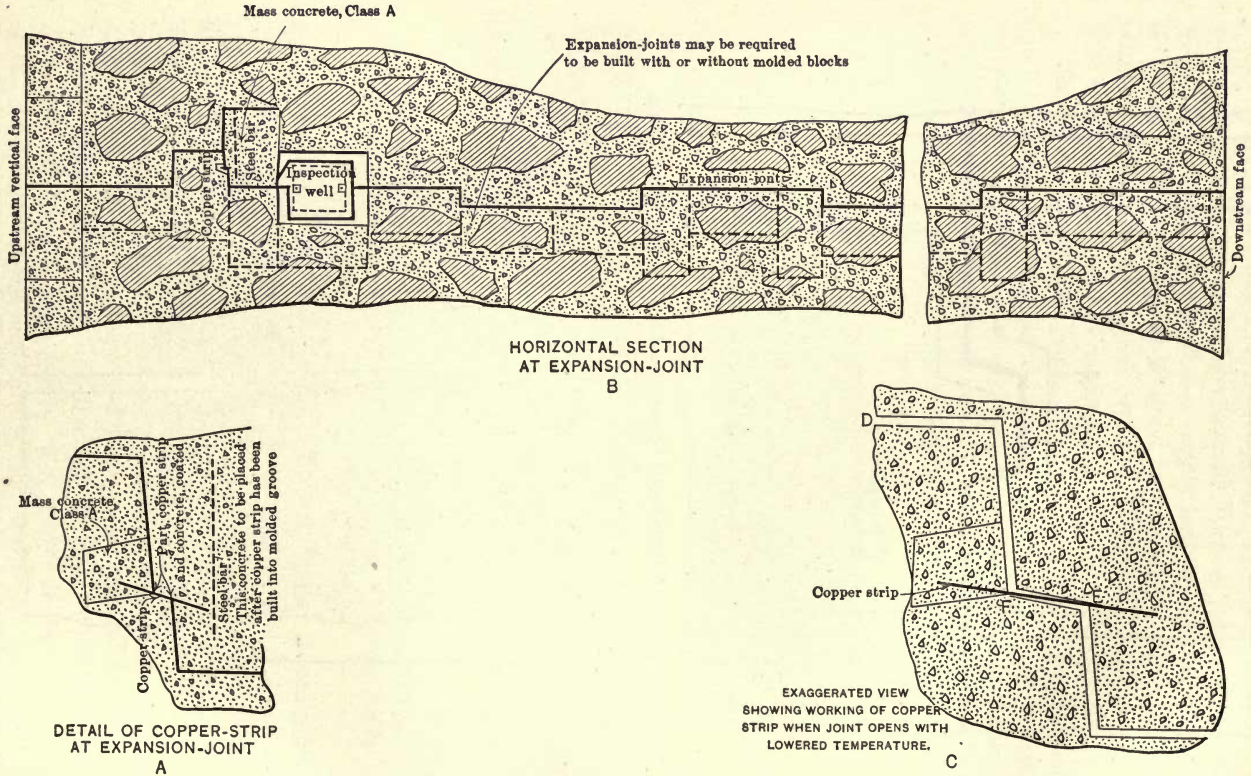


FIG. 55.—Type of Expansion Joint with Internal Cut-off Used in Kensico Dam, Catskill Aqueduct, New York.

After the concrete or mortar in the groove had set, the central part of the projecting strip and the portions of the vertical faces of the masonry against which it rests were coated with hot paraffin or other suitable substance to prevent the adhesion of the strip to the concrete where it crosses the expansion joint. Concrete was then placed and carefully rammed around the projecting strip on the other side of the joint, care being taken to thoroughly clean the uncoated portion of the strip before placing the concrete. The strips were built up in sections, riveted together with copper rivets.

The operation of this cutoff is as follows: As the masonry contracts, the expansion joint is, of course, enlarged. Water entering at *D* (Fig. 55, *C*) will proceed as far as the junction of the copper strip *E* and the masonry. From there the water cannot get around

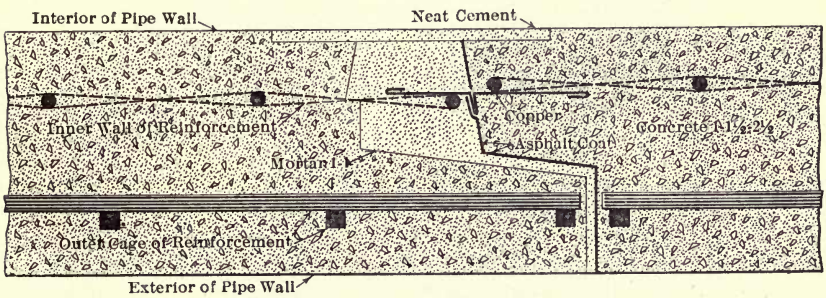


FIG. 56.—Expansion Joint with Internal Cut-off Used in Reinforced Concrete Waterpipe. (Patented.)

to the other junction at *F*. Hence, it remains there and freezes when cold weather sets in. The effect of this freezing and the consequent thawing is cumulative upon the structure in that when ice forms the water expands, exerting a force in the same direction as the contraction of the masonry, caused by the lowering of the temperature. On the other hand, when thawing sets in the mobility of the water returns and the masonry expands unimpeded. The copper strip being placed near the upstream face keeps the rest of the joint practically dry.

The internal cutoff is not limited only to large and massive structures, but may be and has been used very successfully on reinforced concrete pipes for conveying water even under pressure. These pipes are usually made in small lengths, 3 to 10 feet, of scientifically graded aggregate mixed in about the following proportions, $1 : 1\frac{1}{2} : 2\frac{1}{2}$. The connection between lengths is made in the form of an expansion joint, such as shown in Fig. 56, which is patented. This expansion

joint has an internal cutoff in the form of a strip of soft copper cast in the spigot end and passing clear around the pipe, being crimped as shown to permit the longitudinal movement of the sections. The other end is set in mortar rammed into the joint from the inside, and protected with a coat of neat cement, as shown. The joints are made free to open and close by the application to the face of the spigots of a bituminous paint.

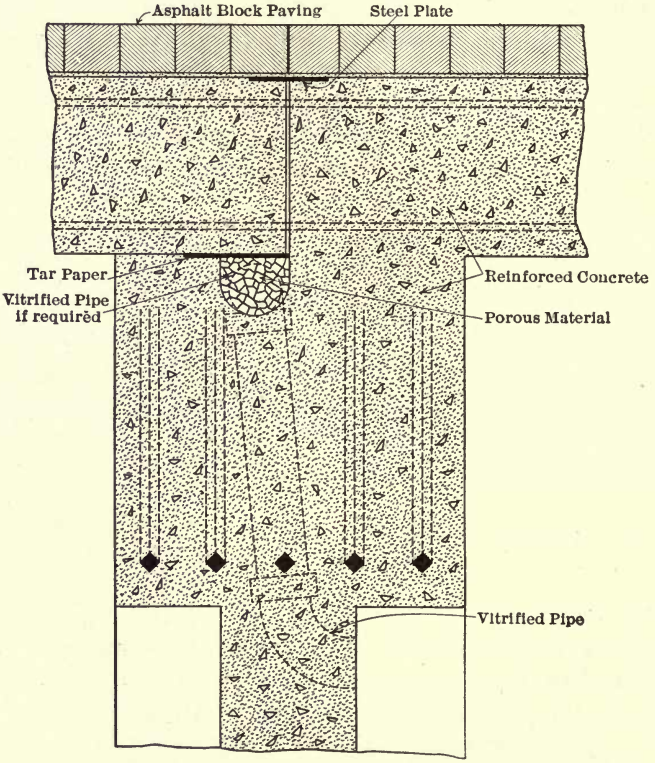


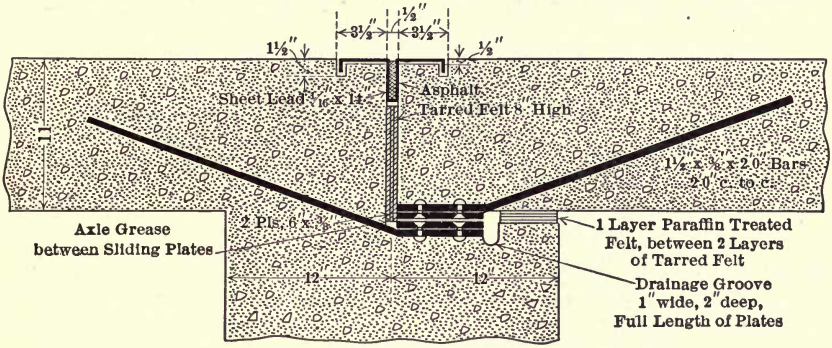
FIG. 57.—Detail of Expansion Joint for Bridge Floor.

An expansion joint in which the water is not only prevented from entering, but is quickly drained off if it should enter, is shown in Fig. 57. This was also used on work connected with the Catskill Aqueduct in New York City. Fig. 58 shows another joint of this type (sliding expansion joint) unique in its design, adapted to and used on the road slabs and sidewalks of the concrete arch bridge in Kansas City, Mo.* A similar joint, modified so that sliding is

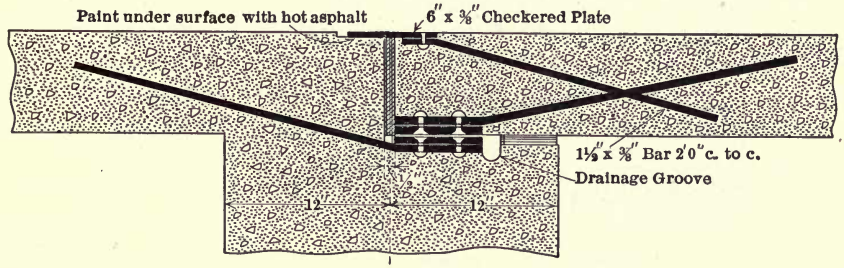
* Engineering Record, Vol. 75, No. 3, January 20, 1907, p. 109.

obtained by means of short pieces of old rails imbedded in the base of slabs and top of piers and abutments, was used on a double-track concrete railroad bridge over the Okaw River in Illinois.*

The external cutoff is much used by railroad engineers for retaining walls and deserves a wider application than it at present enjoys. This cutoff usually consists of a fold formed by laying the membrane



ROAD SLAB EXPANSION JOINT



SIDEWALK EXPANSION JOINT

FIG. 58.—Road Slab and Sidewalk Waterproofed Expansion Joints Used in Floor of Concrete Arch Bridge over the Blue River, Swope Park, Kansas City, Mo.

of whatever material is being used for the waterproofing, over a 1-inch pipe at the joint in the concrete to allow for the expansion in the structure. The pipe is removed after the mat is completed. This mat is then covered with a protective coat of mortar or concrete, and sometimes with mastic. The external cutoff type of expansion joint shown in Fig. 59 was designed by H. J. Finebaum, engineer,

* Engineering News-Record, Vol. 80, No. 8, February 21, 1918.

and used on the new Hill-to-Hill bridge at Bethlehem, Penn.* It consists of two pieces of copper held in the concrete by lugs made by bending back the split ends of each piece and placed on each side of the joint with one end projecting through a groove in the concrete beyond the inside face of the wall. These protruding ends are then bent over to hold a copper flashing piece across the joint between the sections of the wall. The flashing and straps are then

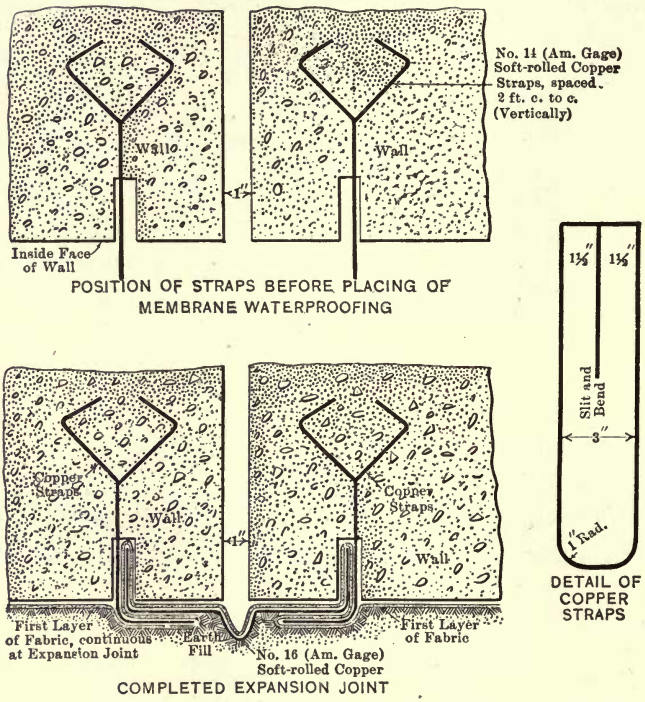


FIG. 59.—An External Cut-off Type of Expansion Joint Used on the new Hill-to-Hill Bridge at Bethlehem, Penn.

bound together, as shown, with the waterproofing fabric, against which the fill is placed. A thin masonry protective cover would be of advantage to the waterproofing fabric. In place of the copper straps the grooves might be filled with mortar with better assurance of watertightness.

Physical-acting Expansion Joint Fillers. Various materials are needed for filling expansion joints such as those considered above,

* Engineering News-Record, Vol. 80, No. 8, February 21, 1918.

and their properties must differ in accordance with the uses they are put to.

There are on the market numerous expansion-joint fillers, but comparatively few possess all of the requisite properties for such a material. The essential properties are (1) to be chemically unaffected by the elements; (2) to completely fill the joints at all temperatures; (3) to constantly adhere to the two sides of the joint; (4) to be elastic, plastic and cohesive at climatic temperatures.

As with many waterproofing materials so with many expansion-joint fillers, their composition is usually kept secret and carefully guarded, even from the purchaser. Therefore the only assurance one has of obtaining the right materials is the selling companies' guarantee; or else the architect, engineer or contractor must resort to chemical analyses and physical tests, and though these tests are quite expensive, it is the safest way. On large engineering work this is very important and on building construction quite essential.

In this connection it is of material interest to know that the chief cause of failure of joint fillers is loss of their sticky condition. This occurs for the following reasons: (1) Evaporation of solvents with the consequent hardening of the material; (2) loss of light oils due to capillary action with the consequent decrease in volume of the material; (3) leading on of water-soluble material with the consequent porosity of the joint fillers; (4) chemically unstable material with the consequent decay of the joint filler. A material that is immune, at least for several years, from the ravages of these four agents makes an ideal joint filler.

It is common knowledge that such materials as tar compounds and blown asphalts* are extensively used and make good expansion joint fillers for many purposes. But their indiscriminate use in the past was followed by many failures. Investigation beforehand would have obviated these disappointments. It would have disclosed the fact that many tar compounds (made for this purpose) leach out all too soon, and that blown asphalts are but short-lived when exposed to the elements. Various putties are used as joint fillers, but unless the liquid part is of such nature and consistency that it will not evaporate or be absorbed, these mixtures will harden and shrink, as will also those containing animal and vegetable materials. Hence the necessity for thorough testing of these products.

* Refined asphalts acted upon by steam or air infused through its mass, which process produces a certain amount of oxidation in the asphalt, resulting in greater toughness of the product.

A commonly used joint filler for joints between steel and concrete (such joints usually being shaped like a "V," or sometimes rectangular) is a good grade of medium hard refined asphalt, mixed with from 5 to 10 per cent of grahamite, depending upon the melting-point desired for the final product. Such a mixture is tough, rubbery and durable. At ordinary temperatures it is hard, but elastic. In applying this compound, it must be melted and poured into or mopped over the joints.

Bituminous mastics are also much used for filling V-joints and for roof flashings with good results. These are usually made of medium-consistency coal-tar pitch or asphalt, mixed with about 20 per cent of cement or limestone dust and asbestos. A mixture of about 45 per cent pine-tar pitch, 30 per cent of petroleum oil and 25 per cent of fiber asbestos, is another extensively used filler for the same purpose.

For certain types of concrete structures such as retaining and abutment walls, a mixture of clay and oil in various proportions is sometimes used as an expansion joint filler. The vertical joint in these structures is usually a plane of weak-bond with an enlarged space near the back of the wall shaped either as a rectangle or a triangle, and it is in this space that the joint filler is placed. The rest of the joint is closed up by the insertion of from one to three plies of treated felt, usually nailed to the face of the green concrete, and against which the new concrete is poured in forming the wall. The specific object of the joint filler is to intercept any percolation of water along the joint.

Another joint filler usable for the same purpose and also for roof flashings, is composed of coal tar and powdered slate, in equal parts by weight. This mixture is applied cold with a trowel.

The following compounds are very serviceable for filling horizontal joints in masonry because they remain elastic at comparatively low temperatures. However, all the bituminous fillers must be completely encased, as they have a constant though imperceptible, flowing tendency, and will actually flow away in time unless prevented. Many expansion-joint failures are traceable to the neglect of guarding against this. The degree of hardness for all bituminous joint fillers is based on climate and local conditions. Usually these types of joint fillers also require preheating and pouring during application.

(1) A Mexican petroleum of about 18 deg. to 21 deg. Baumé, refined so as to leave the heavier oils with the basic asphalt, then blown with compressed air until it has a melting-point of about 175

deg. Fahr. (79.5 deg. Cent.) by the Cube-in-water method. To apply this material it must be heated and poured into, or mopped over, the joint.

(2) Any good-grade refined asphalt of medium consistency to which is added about 5 per cent of stearin pitch and then boiled down to a dense consistency. This material is melted and poured into the joint when applied.

(3) A blown refined Mexican asphalt mixed with about 3 per cent of gilsonite. The asphalt used in making this mixture should melt at about 140 deg. Fahr. (60 deg. Cent.) by the Cube-in-water method, and the mixture at about 175 deg. Fahr., by the same method. The kind of asphalt used governs the percentage of gilsonite to be added; for example, a California asphalt would require about 10 per cent gilsonite. The amount also depends on the climate and local condition of the work.

(4) A refined Trinidad asphalt having a melting-point of about 200 deg. Fahr. by the Cube-in-water method, 88 per cent; gilsonite 7 per cent; and grahamite 5 per cent. This mixture is especially applicable to warm climates.

(5) Any good-grade refined asphalt of medium consistency, 80 per cent; linseed or China wood oil 10 per cent; and fine mineral matter (but no sand) 10 per cent.

(6) A petroleum residuum in the form of a grease (petrolatum), for instance, and free of light or volatile oils makes one of the best joint fillers for V-joints of the type shown in Fig. 129.

Chemical-acting Joint Fillers. Chemical joint fillers, that is, those compounds that become operative only after chemical action has proceeded in their substance while embedded in the joint, are not really expansion-joint fillers. But they are considered here because they are a means of making watertight joints in engineering structures.

For calking joints in steel and iron tunnels, especially those of the segmental type (see Fig. 136), materials of the following formulas have been found serviceable.

(1) Powdered pig iron, mixed with half as much lime, a quarter as much of powdered sand, and about one-eighth as much of salammoniac. This gives a hard, waterproof, joint filler.

(2) Eighty parts fine iron borings, one part salammoniac, two parts flour of sulphur, all by weight and mixed to a paste. This mixture forms a quick-setting joint filler.*

(3) The following mixture is a slow-setting joint filler: Two

* Molesworth's Pocket Book of Engineering.

hundred parts fine iron borings, two parts salammoniac, one part flour of sulphur, all by weight and mixed to a paste. This is preferable to the former, if the joint is not to be put into use immediately.

(4) A rust joint can be made by mixing ten parts of iron filings and three parts of chloride of lime to a paste with water. This material, when applied to the joint, will harden in about twelve hours.

(5) For some time past steel joints have been made watertight by the application of a paste composed of powdered pig iron and water only. But an accelerative oxidizing agent is now usually added and preferred.

The joints of steel tanks and all manner of steel and iron construction where rigidity is practically a property of the structure can be made watertight by properly calking with a steel calking chisel (see Fig. 115). In fact, this is the common and very successful practice at present. Lead wool, introduced a few years ago, has been successfully used without oakum on similar work, and in special cases, as when used for calking joints in structural steel work where watertightness is an essential feature of the structure.

It is often necessary to make floor joints of buildings watertight so as to prevent leakage and consequent defacement of the ceiling below when the floor above it is washed. A compound well adapted for filling such joints, and for filling knot holes in wooden floors and for other similar purposes, is made of five parts of fresh cheese (the so-called Dutch or cottage cheese), one part of unslaked or pulverized lime, both by volume, kneaded together to a stiff dough. This mixture becomes stone-hard, and is insoluble in water. By the addition of mineral colors, such as raw or burnt sienna or umber, yellow or red ochre, Venetian or Indian red, this putty can be colored to any desired shade.*

* "739 Paint Questions Answered," published by the Painter's Magazine of New York, 1904.

CHAPTER V

WATERPROOFING MATERIALS

Selection and Adaptability of Materials. There are on the market numerous waterproofing materials, but comparatively few are extensively used. We shall examine the most important of them, however, to determine their general properties whence we will be able to better understand their use and adaptability for the different systems of waterproofing in which they are employed. The system of waterproofing and the method of application usually determine the character or kind of material to be used, while both the material and the system of waterproofing are dependent on the type of structure to be waterproofed. For, obviously, an existing structure presents different conditions and waterproofing possibilities from one in the course of construction. Again, a tunnel or subway presents different conditions and difficulties than does a building or bridge. Hence the need for different waterproofing systems, methods and materials. Of course, where several materials are equally good, or methods equally applicable, then cost governs. A low first cost, however, is not necessarily the most economical, and it behooves the architect, engineer and contractor to be calculating and cautious in this regard.

Materials for Different Systems of Waterproofing. Nearly all waterproofing materials readily fall under the six systems of waterproofing previously considered, namely: (1) "surface coating"; (2) "membrane"; (3) "mastic"; (4) "integral"; (5) "self-densified concrete"; (6) "grouting process."

Each system however, has certain materials best adapted to itself as, for example, in the "surface coating" system, are used:

(*a*) Scores of patented and secret compounds.

(*b*) Coatings of elaterite, paraffin (oil and solid), mastic, tar, asphalt, and mixtures of these, cement, cement grout, neat cement, and mixtures of caustic potash or soap and alum.

(*c*) Paints composed of suet, lime, asphalts dissolved in naphtha, in benzine or mixed with linseed oil, and other hydrocarbons.

(*d*) Enamels consisting of mixtures of linseed oil and rosin or

bitumen; solutions of bakelite, and proprietary bituminous compounds.

In the membrane system are mainly used:

a. Bitumens
- Asphalt
  - Natural (refined).
  - Artificial (Asphalt-petroleum residuum).
  - Proprietary.
- Pitch*
  - Coal-tar.
  - Oil-tar.
  - Proprietary.

b. Sheetings
- Asphalt saturated felts, papers and fabrics†
- Coal-tar pitch saturated felts, papers and fabrics.
- Oil-tar pitch saturated felts, papers and fabrics.
- Saturated asbestos-felts, asbestos-covered sheet metal.

c. Metals
- Plate steel.
- Cast steel.
- Cast iron.
- Sheet lead, sheet tin, sheet copper, sheet iron.

In the mastic system are used:

(*a*) Coal-tar pitch sheet mastic, asphalt sheet mastic.

(*b*) Brick-in-mastic courses, tile-in-mastic courses.

In the " integral " system are used:

(*a*) Scores of patented and secret compounds.

(*b*) Fattening and void-filling materials, such as hydrated lime, colloidal clay, mixtures of iron and salammoniac, stearin and stearates, gelatinous and bituminous compounds, powdered calcium minerals, and combinations of some of these; also, graphite and petroleum oils.

In " self-densified concrete " are used: (*a*) All the well-known mineral aggregates, as stone, gravel, sand and cement, plus experienced labor and careful supervision.

In the " grouting process " are used:

(*a*) Patented and special cements.

(*b*) Portland or natural cements (either as neat cement, or with sand as grout, and either wet or dry).

All of the above materials may again be approximately grouped under the general terms of " chemical " —and " mechanical "— act-

* Pitch is a general term including asphalts and many other substances of a hydro-carbon nature, but by usage in the waterproofing field has come to be regarded as the designation of coal-tar products, especially coal-tar pitch.

† Fabrics include Jute, Paper and Cotton (Burlap), also Cotton drill.

ing materials depending on whether they act directly or indirectly as waterproofing agents, i.e., whether they act through a chemical or mechanical change or adaptation, either in their own structure or the body of the concrete. This is not always certain or easy to determine, but the following division is sufficiently correct for all practical purposes.

(*a*) Materials acting chemically as waterproofing agents:

Soap, alum, caustic potash, suet, stearin and stearates, rosin, calcium, minerals, linseed oil, lime, hydrated lime,* salammoniac, powdered iron, Portland cement, natural cement, Puzzalon cement, sand cement and neat cement.

(*b*) Materials acting mechanically as waterproofing agents:

Paraffin, asphalt, elaterite, gilsonite, grahamite, tar, bakelite, coal-tar pitch, oil-tar pitch, mastic, bituminous paints, colloidal clay, graphite, gasoline, benzine, naphtha; treated paper, paper burlap; treated asbestos felt, treated rag and pulp felt, jute burlap, fabric, cotton drill; cast iron, plate steel and all sheet metal, water, sand, gravel, stone, cement grout and cement coatings.

Nature of Materials Acting Chemically as Waterproofing Agents

A certain amount of knowledge regarding the nature of these materials is essential to the proper understanding of their use and application in the art of waterproofing. It was therefore deemed expedient to make the following notes relating to, and affecting their use in waterproofing engineering. It is not intended that these remarks be exhaustive, but merely explanatory of the properties and uses of the more important materials.

Alum. Common alum is a white powder or crystalline substance consisting of a double sulphate of aluminum and potassium. It is found native as kalinite and manufactured. It is soluble in boiling water in equal parts by weight, but only about 5 per cent in water at 60 deg. Fahr. (15.5 deg. Cent.). In the form of a solution it is brushed on a masonry or concrete surface over a previous coat of soap solution with which it combines chemically forming a stearate of aluminum which acts as a void-filler and also forms a water-repellent coating.

Calcium (compounds). Calcium is a lustrous, white, very ductile, and malleable metal about as hard (and scarce in the pure form) as pure gold. It has the peculiar property of decomposing water

* Also acts in part at least as an inert void-filler.

with evolution of hydrogen. Calcium compounds, are salts of calcium and it is these that are used in waterproofing. They occur largely diffused in nature in the form of chalk, marble, limestone, coral, etc. As calcium sulphate or calcium carbonate (marble) it is used in powder form in the manufacture of dampproof paints. These compounds when mixed with cement and aluminum, form many secret (?) waterproof and dampproof surface-coating compounds.

Casein. Casein is an albumen found in the milk of animals. When milk curdles it is due to the coagulation of the casein present, which averages about 3 per cent. Acetic acid or a bit of rennet will produce curdling and the casein separates as curd. Casein is not easily affected by heat. When moist and fat-free, it forms insoluble precipitates with quicklime, borax or strong sodium silicate solutions. In any of these forms it is used as a waterproofing cement.

Caustic Potash. Potassium hydroxide is commonly called caustic potash. It is a white, solid substance, very easily melted and quite soluble in water or alcohol. In solution it possesses, in the very highest degree, the properties termed alkaline. In waterproofing it is sometimes substituted for soap as a surface coating, or it is used with various chemicals in secret (?) waterproofing compounds.

China Wood Oil. China wood oil is obtained from the seeds of the fruit that grows on the wood oil tree of the Aleurites species of China and Japan. These trees are of comparatively rapid growth, with trunks of light, soft wood. The oil is a rapid drying one and is largely used in the manufacture of varnish and waterproof cements. It is often advantageously substituted for linseed oil in the manufacture of some waterproof paints and varnishes. It is slightly heavier than the boiled or raw linseed oil, its specific gravity being 0.944.

Hydrated Lime. Hydrated lime is a finely divided white powder made of ordinary lime by the addition of just sufficient water to insure complete slaking, and so that the heat generated will evaporate all the excess water, leaving the product dry. There are several grades made, the difference being mainly in the calcium and magnesium content; but this is dependent on the source of the carbonate. High magnesium lime, though it slakes and sets slower, is superior in other important properties to the high calcium limes. For ordinary purposes hydrated lime is used for and in precisely the same way as common lime. In waterproofing it is used to a greater extent than common lime as it is much more effective, because when

properly manufactured, it slakes and mixes more thoroughly in the concrete (see Chapter III).

Iron (Powdered). Iron is an element abundant in nature and universal in its existence and application. For waterproofing purposes pig iron is used in granulated or powdered form. When mixed with appropriate chemicals, as, for instance, salammoniac, sulphur and even cement, it forms a surface-hardening substance for concrete and mortar. When mixed with water, it forms and is often used as a "rust joint." In this manner it is sometimes used in calking joints in cast-iron tunnel linings. It can readily be tempered in its oxidizing action by mixing it with Portland cement.

Lime. Lime is a white substance resulting from the burning of limestone in kilns until the carbon dioxide is driven off as a gas, leaving the calcium oxide, or lime, which slakes when water is added to it. On exposure to the air it sets and hardens, by reverting to its original state, i.e., it takes in carbon dioxide from the atmosphere. It is often incorporated in concrete and mortar to reduce their porosity, or mixed with certain salts in cement mortar to form a waterproof mortar coat. But its benefits are limited as well as its use, because it will not set under water.

Linseed Oil. Linseed oil is obtained from the seed of flax either by pressing or by extraction with naphtha or other solvents. It is used either raw or boiled; the boiled toughens or dries quicker in air. The unadulterated linseed oil possesses a characteristic but disagreeable taste and odor. Its color is light amber or greenish yellow. The boiled oil dries more rapidly on exposure to the air than the unboiled and is mostly used for interior work, the raw for exterior work. Both kinds thicken and toughen with time, and dry by oxidation, i.e., they have the property of absorbing oxygen and forming a tough and elastic substance which, however, eventually deteriorates. It is often used to flux asphalt and coal-tar pitch, to make surface coatings for dampproofing and waterproofing purposes.

Natural Cement. Natural (or Roman) cement is a very fine powder, made from clinkers resulting from the burning, at a comparatively low temperature, of an impure limestone, containing from 15 to 40 per cent of silica, alumina and iron oxide. It was first manufactured in England in 1796 by James Parker. This cement is comparatively slow setting and is not as widely used as Portland cement. Neither is it as reliable, because the proportions vary not at will, but according to the nature of the source. It is not generally used where a very impervious concrete is desired.

Neat Cement. Neat cement is a term applied to a paste-like mixture of cement and water regardless of proportions. It is applicable to any kind of masonry both above and below ground surface in the form of a thin coat or surface wash. The thicker the coat however, the more impermeable it is and hence the more effective as a waterproofing agent. Neat cement is often used for grouting purposes especially where rock seams or cracks are small but extensive.

Portland Cement. Portland cement (named for its resemblance, when set, to limestone quarried at Portland Isle, England, where it was first made in 1811, and patented by Joseph Aspdin, a bricklayer, of Leeds, England, in 1824), is a very fine powder made from clinkers resulting from the burning, at a temperature of about 3000 deg. Fahr. (1649 deg. Cent.), of a finely ground artificial mixture of lime,

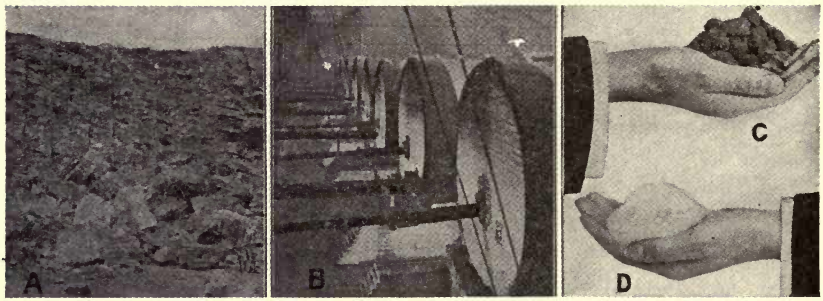


FIG. 60.

A. Cement Rock, as it Appears in Nature.
B. Cement Materials being Burned in Rotary Kilns.
C. Cement Clinker as it Comes from the Kilns.
D. Cement, Ground Fine for Use.

silica, alumina and iron oxide in certain definite proportions (see Fig. 60). This combination is made by mixing limestone or marl with clay or shale in the proportions of about three to one respectively. The finer the cement the more impervious is the concrete made with it. Most concrete construction is done with Portland cement.

Puzzolan Cement. Puzzolan cement is a mechanical mixture of powdered slaked lime with either a volcanic ash or a blast furnace slag. In the form of a mixture of powdered slaked lime and volcanic ash, puzzolan cement was first used by the Romans in their building construction. Unlike the other cements, this mixture is not burned but is finely ground. The resulting powder is somewhat superior

to other cements in its resistance to the action of sea water, for which reason it is often used in maritime construction.

Resin. Resin is a solid or semi-solid substance composed of carbon, oxygen and hydrogen, mainly of dark amber color, homogeneous and translucent, though some varieties are colorless and transparent. It is mostly of vegetable origin. Common rosin is a similar substance remaining when turpentine, from gum or pine resin, is distilled until the water and volatile oils are expelled. Resin is insoluble in water but soluble in alcohol, ether and various oils. Rosin is used extensively as a flux in inexpensive paints, varnishes, dampproofing and roofing compounds in which it acts as a filler and for making soap. Nearly all surface coating compounds contain resin or rosin, where it is often used as an adulterant and tends to make the compound brittle.

Salammoniac. Salammoniac ($NH_4 \cdot Cl$) is ammonium chloride, a white crystalline substance, obtained from the ammoniacal waters of gas works by adding sulphuric acid and then sublimating the sulphate thus formed with sodium chloride, or by absorbing ammonia gas in hydrochloric acid, also by heating ammonium sulphate with common salt. It is freely soluble in cold water, but much more so in hot water. In waterproofing it is mainly used as an oxidizing agent, particularly for powdered iron, with which it is often mixed for calking joints in steel and iron-lined tunnels, and in modified form for hardening concrete surfaces, which tends to make these surfaces water tight and dustproof.

Sand-cement. Sand- or silica-cement is a mechanical but intimate mixture of Portland cement with a pure clean sand, very finely ground together. In the best grade of sand-cement the proportions of cement to sand are 1 : 1 but as lean a mixture as 1 : 6 has been made. This cement, efficiently proportioned, has been and may well be used for making impervious concrete, providing the equally important matters of grading and mixing are properly attended to.*

Soap. Soaps are metallic salts of the higher fatty acids or, more particularly, compounds formed by the substitution of the alkalies, sodium and potassium, or magnesium and aluminum for the glycerine in common fats. Soaps containing sodium harden on exposure to the air and are known as hard soaps, and those containing potassium absorb water under the same conditions and tend to liquefy, hence they are known as soft soaps. The sodium and potassium soaps

* It is of course beyond the scope of this book to discuss in detail the respective properties of cements. Further and full information will be found in any standard book on concrete.

are water-soluble, the magnesium and aluminum soaps are water-insoluble. In waterproofing the soaps are used (1) by being dissolved in water and the solution brushed on a concrete or other masonry surface and then coated with an alum solution with which it unites chemically forming an insoluble stearate (soap) of aluminum which acts as a void filler and water repellent; (2) by being suitably mixed with colloidal matter it is often incorporated in concrete to aid in increasing its density. Castile soap is most generally used in making soap solutions, but any of the common soaps in everyday use may also be used. Aluminum soaps are used for making various proprietary integral waterproofing compositions.

Stearate. Stearate is a salt of stearic acid. Stearates, such as, for example, ammonium stearate or lime stearate, are used as integral waterproofing compounds. They have the consistency of hard soap and are mostly insoluble in water but are decomposed by most acids. Ammonium stearate can be made by taking stearic acid and combining it with ammonium hydroxide in the presence of considerable water or water-yielding material. This forms a more or less air-unstable quasi-soap of a water-soluble nature. This soap-like material, when brought in contact with cement in the presence of moisture, reacts and forms a water-insoluble stearate, with water shedding properties, while the alkali, that is, the ammonia, being liberated as a volatile, supposedly disappears in time.

Stearic Acid. Stearic acid is a derivative product of the more solid fats of the animal kingdom and vegetable fats, especially those of cacao-beans, and certain African nuts. It is prepared from mutton suet or cacao fat by saponifying* the fat with soda-lye. Pure stearic acid has a specific gravity of 1.00 at 50 deg. Fahr. (10 deg. Cent.). It melts at 156 deg. Fahr. (69 deg. Cent.) to a colorless oil, which cools into a solid, white scaly mass. It is insoluble in water and is much used for making dampproofing varnishes and integral waterproofing compounds.

Stearin. Stearin, a solid substance at ordinary temperatures, is the chief ingredient of suet and tallow. Stearic acid is obtained from it by the application of steam to the harder fats, and chemical treatment. Stearin is used for making various waterproofing materials, and is often mixed with asphalt to make proprietary joint-filling compounds.

* Saponification is the process by which the fatty acids and glycerine are separated with the latter set free; that is, the process of converting a fat or oil into a soap by combination with an alkali.

Stearin Pitch. Stearin pitch is an animal by-product obtained from stearic acid in the manufacture of candles. It is used as a coating for some smooth-surfaced ready roofings, and is a very stable material, being practically unaffected by the action of the sun.

Suet. Suet is animal fat, especially the harder and less fusible fat about the kidneys and loins, and whose chief ingredient is stearin. It is cheap and when chemically treated is used as a water-repellent for mass concrete. When mixed with colophony in certain proportions it is used as a dampproofing and as a water-repellent varnish.

Nature of Materials Acting Mechanically as Waterproofing Agents

Asbestos. Asbestos is a fibrous mineral (see Fig. 61, *A*, *B*) derived from certain igneous and metamorphic rocks (by the action

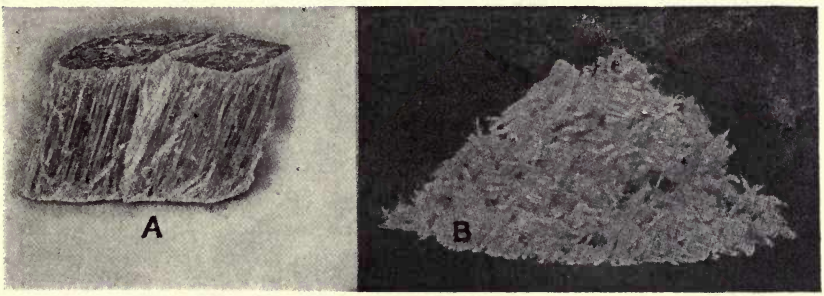


Fig. 61.

A. Asbestos as it Comes from the Mines.
B. Asbestos Fiber as Used with Bitumen to Form Plastic Compounds.

of heated waters, in nature) and is chemically known as a hydrous-magnesium silicate. Commercially asbestos has been used since ancient times, but its discovery is attributed to the Romans. It is incombustible and non-perishable and because of its fibrous nature is often incorporated in various bitumens to form a plastic waterproofing cement. It is also powdered, and in this form it is used as a filler in dampproofing paints. It is also used for making asbestos felt which is often saturated in the same manner as roofing felt and also used for the same purpose. As such it is, however, much more expensive. It is also made into roof shingles.

Asbestos Felt. Asbestos felt is made of about 95 per cent asbestos with some form of sizing to permit its being rolled into long thin sheets of various widths and thicknesses similar to roofing felt. It

is weaker than the ordinary felts, does not saturate as well, and has not as wide an application, but it will not decay and is fireproof while the felts and fabrics are not. This latter property is inherent in the asbestos proper. Asbestos felt, saturated with bitumen, is mostly used for roofing, and is ordinarily applied only by the manufacturer. Sheet iron covered on both sides with asbestos felt is used as a form of fireproof and waterproof roofing.

Asphalt. Asphalt is a solid or semi-solid native* bitumen found in a natural state, or produced artificially, as petroleum residuums. In its origin it is decomposed vegetable matter comprising mainly carbon and hydrogen of complex molecular construction, but also containing oxygen, sulphur and nitrogen in very small proportions. As found naturally, asphalt is not commercially available even after the impurities are removed, being usually too hard and brittle for waterproofing purposes. This is ordinarily remedied by softening or fluxing with various petroleum oils, which fluxes have an important effect upon the finished product. The fluxes should be sufficiently stable to insure against too rapid hardening of the fluxed asphalt. To avoid the process of fluxing, which requires skill, a straight refined asphalt from petroleum oil of an asphaltic base is used. Pure bitumen has a density less than water, but in consequence of impurities mixed with it, its specific gravity varies from 1.0 to 1.7. The distinguishing characteristics of all bituminous substances are their elasticity and binding power (or adhesiveness), their considerable immunity against attack by water and their solubility in oils and certain other organic compounds. Most waterproofing asphalts are elastic at ordinary temperatures, slightly viscid at low temperatures and usually liquid at comparatively high temperatures. Asphalt is quite soluble in petrolic ether, and entirely soluble in carbon bisulphide. Aside from the paving industry where nearly all varieties of asphalt are used and the varnish industry where the very best and purest varieties are used, it is chiefly used as a saturant, coating and bonding material for felts and fabrics in the membrane system of waterproofing, and as binding material in the mastic system of waterproofing.

Bakelite. Bakelite is an artificial coal-tar product produced by warming together equal weights of phenol and formaldehyde and a small amount of an alkaline agent. The resulting mixture separates into two layers, the lower of which, when heated above 212 deg.

* The term "native bitumen" implies that the natural asphalt, such as Bermudez or Trinidad asphalt, requires treatment merely for the removal of water and extraneous organic and inorganic materials before using.

Fahr. (100 deg. Cent.) and worked under a pressure of 50 to 100 pounds per square inch, results in a hard, solid, inelastic mass known as bakelite, from its inventor, Dr. Leo Baekeland. This mass has a specific gravity of 1.25 and is an excellent insulator, but when dissolved in neutral petroleum oil is used as a varnish for dampproofing and waterproofing purposes.

Benzine. Benzine is a light volatile petroleum oil used as a solvent for fats, gums, resin and bitumen. Bituminous solutions are formed with this petroleum oil and used as a surface coating which penetrates into the pores of the concrete to which it is usually applied with a brush. After evaporation the bitumen remains in the pores and on the surface in the form of a thin coat.

Benzol. Benzol (or benzene), C_6H_6, is a volatile, colorless, fluid hydrocarbon, obtained as a by-product from the distillation of coal-tar and water-gas tar, and from petroleum. It was discovered first by Faraday, in 1825, in oil gas, and by Hofmann, in 1845, in coal-tar. Benzol is an active solvent for fats, resins, most bitumens and is used for that purpose in waterproofing.

Bituminous Paints. Some bituminous paints are made of solutions of liquid paraffin in either asphalt or coal-tar pitch, or by mixing bitumen, while hot, with some drying oil such as linseed oil, or China wood oil with either of which the bitumen readily enters into solution. Similar products are obtained by mixing paraffin and petroleum with naphtha, benzine or gasoline. Some of these paints are applied hot, others cold. Some will adhere to a wet surface or a surface under water, but most of them need a thoroughly dry surface. They are in general quite durable, cheap and easily applied.

Burlap. Burlap is made of jute, which is the fiber obtained from the inner bark of the Asiatic plant, genus Corchorus, of the Linden family. It is a very cheap fiber, woody in its nature and more perishable than flax. It is mainly grown in the northeast section of India, and is manufactured in Calcutta, but the best grades of burlap are manufactured in Dundee, where the industry was first started on a commercial scale in 1838. The burlap is woven in many widths and has considerable tensile strength. It is sold by weight. The most used varieties for waterproofing purposes are 7, $7\frac{1}{2}$, and 8 ounces per square yard. This weight, however, is materially affected by the moisture content, which under normal conditions, that is, at an average relative humidity of 70 per cent, the jute may contain about 14 per cent of moisture by weight. Burlaps of these weights have open meshes, the size of which vary with the weight, as, for example, the 7-ounce burlap is approximately 60 per cent

open, the mesh being about $\frac{1}{8}$ inch square. The size of the mesh decreases with increase of weight. Burlap in the raw state is sometimes used as reinforcement, in the membrane system of waterproofing; but when saturated and coated with asphalt or oil-tar pitch, which preserves it, it is very extensively used in membrane waterproofing.

Cast Iron. The cast iron here considered is that usually used in the construction of tunnels and for tunnel linings. The best castings for this purpose are made of gray iron produced by the cupola process, of the second melting. The castings, called tunnel segments, must be true to pattern and flawless in every other respect. In order to reduce the leakage through the joints to a minimum the castings are faced by machine. Provision must also be made for calking the flanges after the segments are erected (see Fig. 136).

Cement Mortar (Grout). Cement mortar or grout is a mixture of cement, sand and water in any proportion from 1 : 1 to 1 : 6. This mixture is termed mortar or grout when the size of sand does not exceed that which will pass 100 per cent through a 4-mesh sieve, or what is ordinarily called " bird-sand." When it does exceed the $\frac{1}{4}$-inch size, a smaller aggregate is required to fill the voids besides the cement, and this mixture is therefore correctly termed concrete. Cement grout of the proportion 1 : 1 or 1 : 2 is used very successfully in the grouting process and as mortar in the surface-coating system of waterproofing. In the above proportions it is very impervious, but as a coating its impermeability also depends on its thickness. It adheres readily to a roughened surface and is applicable to any kind of masonry.

Clay. Clay is an uncrystallizable silicate of aluminum. It is produced in nature by the disintegration of the various silicates of aluminum in the stones known as feldspars and micas, due to weathering. Clays are usually moist or wet and plastic in varying degrees depending in part on the fineness of the grain and in part on the amount of colloidal substances present. This plasticity may be increased by the addition of water. The fineness and glue-like or gelatinous composition of clay makes it a good inert void filler, and in small quantities is used for that purpose in mineral paint and mass concrete. It is often used as a cutoff in specially constructed expansion joints in masonry structures. In the form of a thick blanket (not less than 4 inches thick) applied to an underground structure, for instance, it can be made a very efficient waterproofing medium for equal mixture of clay and Portland cement is used for a like purpose.

Coal-tar Pitch. Coal-tar pitch is a semi-solid or solid residue resulting from the fractional distillation or boiling of coal-tar. This process removes certain volatile oils and results in a black, more or less viscid residuum product called coal-tar pitch. There are various grades of pitch, the best being used for general waterproofing. In comparison with asphalt, this best grade of coal-tar pitch is harder at low temperatures and more liquid at high temperatures than the asphalt. It is, however, more adhesive at ordinary temperatures and less affected by water than most asphalts; but it is somewhat less durable in air.* Coal-tar pitch contains free carbon, in amounts depending on the method and degree of reduction, and the source of the tar. The more free carbon in pitch up to about 30 per cent the less it is affected by changes in temperature and apparently has more " life " than another with less free carbon.† Coal-tar pitch is extensively used as a saturant, coating and bonding material for waterproofing and roofing felts and fabrics and is in close competition with asphalt for use as binder in the membrane system of waterproofing.

Cotton Drill. Cotton drill, as usually used in the membrane system of waterproofing, is a woven-cotton fabric, weighing not less than 4 ounces to the square yard. This weight of cotton fabric has a thread count of 56 by 60 per square inch. Different grades are made, but those generally used vary in thread count between 34 by 34 and 66 by 68, per square inch, both inclusive. When either saturated, or saturated and coated with bitumen, these cotton fabrics are sold as standard products, but often also under various trade-names. The cheaper grades are somewhat less durable, and the better grades are usually more expensive per yard than most waterproofing felts or jute fabrics. Treated cotton fabric, in comparison with the untreated, gains about 20 per cent in strength due to treatment. It is comparatively close-woven, and therefore, unlike the open-mesh jute fabric which acts only as a reinforcement in the bituminous membrane, it acts also as a waterproofing agent in approximately the same manner that waterproofing felts do, that is, it helps to keep the water out.

Elaterite. Elaterite is a soft, elastic variety of asphalt (hydrocarbon), resembling India rubber, mined in Utah and Colorado, U. S. A., and in several places in England, notably in Derbyshire. It is subtranslucent, has a brownish color, and a specific gravity varying from 0.9 to 1.0. It is also known as " mineral rubber."

* American Society for Testing Materials, June 24, 1913.

† American Railway Engineers' Association, Vol. 14, p. 844.

Commercially it is combined with certain petroleum oils, linseed oil, asphalt, gilsonite, and even castor oil (because the latter is a non-drying oil), and used as a surface coat on concrete. The compounds thus formed are quite plastic at all temperatures to which this climate is subject to. Elaterite is very difficult to melt, but in solution with various materials forms a much used dampproofing compound.

Felt (Waterproofing). Felt made for waterproofing purposes is a product composed chiefly of pulp or cotton rags with a little wool; the latter makes the felt open and spongy, and materially increases its saturating power. The first mechanical process for making felt was invented by J. R. Williams, an American, about 1820. It is made in sheet form, usually 36 inches wide, and saturated with asphalt or tar. The asphalt felting has an advantage over ordinary coal-tar felting, in that it does not become brittle under the influence of heat or with age. As now made waterproofing felt comes in several thicknesses and is sold by weight or roll, the standard for the latter being a roll containing 3 or 4 squares, plus 8 to 12 square feet per square extra for laps. The quality of the raw felt is designated by a number as, for instance, No. 23 felt would mean a felt equal in weight to a ream of 480 sheets each one foot square. A No. 28 felt would be one weighing 28 pounds per ream. These numbers also happen to approximate the weight of the felt in grams per square foot, which fact it may be useful to remember. There are soft and hard felts made, hence the word soft or hard must follow each number. The soft felts are usually asphalt treated, the hard ones, tar treated. The soft felts are usually dearer, because they contain more wool. All-wool felt is generally not made because of its high cost, softness and tenderness. A wool content of about 25 per cent produces a felt of good saturating power, and saturation is very essential for the preservation of all the raw felts. Good saturated felts are quite durable, but they lack tensile strength, though they gain about 500 per cent strength due to such treatment. They readily absorb water though, in spite of their saturation.

Gasoline. Gasoline is one of the very volatile distillates of petroleum. It consists of a mixture of several hydrocarbons containing carbon and hydrogen in varying percentages. Its chief use is for fuel, but in waterproofing it serves as the distillate or "carrier" for many bitumens which readily dissolve therein. These solutions are applied cold to the surface of masonry, but mainly for dampproofing purposes. The gasoline penetrates the pores of the masonry surface, carrying with it the bitumen which remains after evapora-

tion. Thus, besides forming a film on the surface the pores are also barricaded.

Gilsonite. Gilsonite is a hard and brittle, native bitumen, mainly found in Colorado and Utah, with a specific gravity of 1.07. It is lustrous black and equally soluble in cold carbon tetrachloride and carbon bisulphide. It is also readily soluble in heavy asphaltic petroleum. When mixed or fluxed, while hot, with certain petroleum residuums (it begins to melt at about 480 deg. Fahr.—249 deg. Cent.) in proportions according to the consistency desired, a rubbery and somewhat elastic but only slightly ductile material is formed. Gilsonite is mainly used for making dampproof paints and varnishes and proprietary waterproof compounds mostly for surface coatings. It is sometimes mixed with a light asphaltic residue to bring the latter's consistency up to certain specification requirements for particular waterproofing purposes.

Grahamite. Grahamite or "Choctaw" is a hard and brittle native bitumen mainly from Oklahoma, with a specific gravity of 1.14. The deposit is now exhausted. It is a dull black and melts only with great difficulty (at about 500 deg. Fahr.—260 deg. Cent.) and therefore has but a limited use. It is slightly soluble in alcohol and partly so in ether, petroleum, and benzol, but almost completely in turpentine and entirely in carbon bisulphide and chloroform. It is used for the same purposes as gilsonite.

Graphite. Graphite is essentially a pure carbon which comes in two forms—flake and amorphous—and found abundantly in nature. It is friable and has an oily quality, for which reason it acts as a lubricant. (Lamp-black or soot should not be substituted for graphite because they have not the same properties.) Graphite when finely ground and mixed with silica and linseed oil is commonly used as a preservative paint for metals. For waterproofing it has a limited use as an integral because of the black color it gives to the concrete. Hydrated lime serves the same purpose, i.e., as a lubricant for the concrete aggregate, without this defect. Graphite enters into many dampproofing compounds.

Gravel. Gravel is an aggregation of water-worn and rounded fragments of rocks, in which quartz is the most common mineral. Included under the name gravel are pebbles ranging in size from $\frac{1}{4}$ inch to 2 inches. Gravel is usually classified according to the largest size pebble which it contains as, for instance, $1\frac{1}{2}$-inch gravel; 1-inch gravel; $\frac{3}{4}$-inch gravel, etc. For making impervious concrete, gravel must be sound and clean. Concrete is considerably densified by using gravel graded from fine to coarse, but the best results follow

when it contains no pebbles that will pass through a hole $\frac{3}{8}$ inch in diameter and none that will not pass through a hole $1\frac{1}{2}$ inches in diameter. No gravel that is all of one size or practically so should be used where impervious concrete is desired.

Jute Fabric. Jute fabric* employed in the art of waterproofing is a burlap saturated and coated with asphalt or coal-tar pitch. When thoroughly saturated and coated it is very much less perishable than raw burlap, while its strength is nearly doubled thereby. It

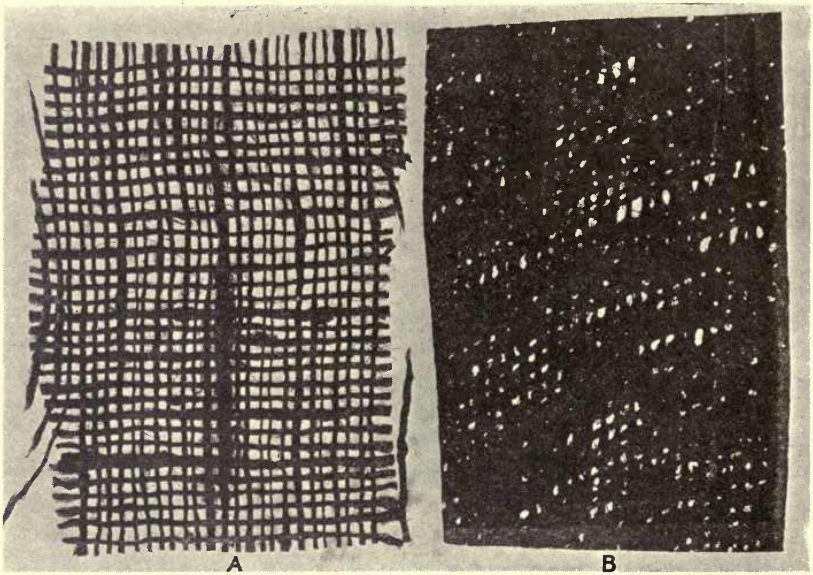


FIG. 62.

A. Seven-ounce Untreated Burlap, Showing open Mesh.
B. Same Burlap, Saturated and Coated with Asphalt.

retains between 35 and 50 per cent of its open mesh after treatment, becomes more pliable, and weighs between 14 and 18 pounds per 100 square feet. It acts as a reinforcement in the waterproofing membrane much the same as does expanded metal in reinforced concrete slabs. It is now very extensively used for waterproofing underground structures, and is in keen competition with felt, which, formerly, was used exclusively. Fig. 62, *A*, shows a photographic reproduction of a piece of 7-ounce raw burlap; Fig. 62, *B*, shows the same piece properly saturated and coated with bitumen.

* "Manufacture, Test and Use of Waterproofing Fabric," Engineering News, September 24, 1914.

Mastic. Mastic employed in the art of waterproofing, is composed of asphalt or coal-tar pitch mixed with cement or limestone dust often also with sand, and all in varying proportions depending on the particular use to which it is put. Mastic may also be made of fluxed natural rock asphalt and grit. The mineral matter in the mastic gives it " body " i.e., makes it more substantial, raises its melting-point, lessens the fluidity and increases its bearing power as compared with the bitumen used. The latter properties depend on the relative proportion of the bitumen and mineral matter. The usual proportions for waterproofing-mastic such as used with bricks to form a brick-in-mastic layer are from 30 to 50 per cent of bitumen, the remainder being equal proportions of sand and cement. The sand used in making the mastic is usually fine enough to pass 100 per cent through a 10-mesh sieve. In some cases, the mastic is used as mortar with bricks for waterproofing floors, walls, roofs and underground structures. It is often used alone to form a continuous sheet an inch or more in thickness, to waterproof subsurface structures. For such use the mastic may contain from 10 to 15 per cent of bitumen, 8 per cent cement, 40 to 45 per cent limestone dust, 25 per cent grit and from 12 to 17 per cent of sand.

Naphtha. Naphtha is a thin white oil obtained mainly from petroleum by distillation and also from the distillation of wood and coal-tar. There are several varieties and grades of naphtha and they are differentiated by their boiling-points and specific gravity but all are hydrocarbons. Commercial bitumen is partly soluble in naphtha but when heated in a steam-jacketed kettle and not thinned out too much, a mixture of the two is obtained in which the part of the asphalt not dissolved is held in suspension. In this form it is used for making bituminous dampproofing paints.

Oil-tar Pitch. Oil-tar pitch is the residue of the distillation of oil tar, which itself is a by-product of the manufacture of oil gas or carbureted water gas. It is produced in the cracking of oil vapors at very high temperatures. This process causes the oils to undergo marked changes and to acquire some of the characteristics found in coal tar. These oils are then distilled down and treated much as is coal tar, resulting in what is known as oil-tar pitch. The free carbon content of oil-tar pitch is low, ranging between 5 and 15 per cent; it is, however, always less viscid than coal-tar pitch, though about equal in its resistance to the action of water and not materially less stable than coal-tar pitch. Its chief use is on roofs of buildings as a roofing binder and sometimes as a saturant for waterproofing felts and

fabrics. Where coal-tar pitch is to be applied as a surface coat, oil-tar pitch is often used as a primer because of its penetrating power, but for this purpose dead oil is preferable.

Paper. Paper was first made by the Chinese, from whom it spread to other races, and was brought to Europe in the Twelfth Century. The first paper mill in America was built by William Rittenhouse, at Roxborough, near Philadelphia, in 1690. There are innumerable varieties of building paper on the market, but in waterproofing only two or three of these are used. These are made of various kinds of wood pulp, rope, rags or wool or from a combination of pulp and rags or wool. None of these papers can be completely saturated with bitumen, but all can be sufficiently saturated to preserve them for a considerable time. Those known as "building papers" are not saturated at all. Some papers are merely coated on one or both surfaces with bitumen. Some are weak in tension, others very strong, and of late a very strong variety of paper has been successfully treated and is sometimes used in place of felt.

Paper Burlap. Paper burlap, as made for waterproofing purposes, is an open mesh paper fabric, similar to jute burlap and sometimes substituted for it. It can be saturated with bitumen only with difficulty. It may be used in waterproofing in the same manner as jute burlap. It comes in several weights and widths and is slightly reinforced with cotton, but it is not nearly so strong as the jute variety. It is also more perishable. By pasting a very thin tissue paper completely over one side of the paper burlap and coating the whole with a tacky asphalt or coal-tar product, it is made into an efficient electric cable duct wrap.

Paraffin (Solid). Solid paraffin is a hard, white, waxlike substance, chemically of the higher hydrocarbons. It is obtained by distillation from petroleum,* but is also found native in coal and other bituminous strata. The manufacture of paraffin was begun in 1851 by James Young, a Scottish chemist. It is very inert, insoluble in water, and can be mixed in all proportions in various oils when in a melted condition but lacks adhesiveness and is useless as a binding material. For waterproofing it is often mixed with asphalt (complete solution therein is essential), or used alone in various ways, e.g., to render fabrics waterproof. When used unblended, as a masonry surface coating it is the most efficient waterproofing medium for the purpose. It is also used in the manufacture of secret (?) waterproofing compounds.

* The Pennsylvania and, in general, the Eastern (U. S. A.) oils are largely made up of compounds of the paraffin series.

Paraffin Oil. Paraffin oil is a by-product of the manufacture of paraffin. It is a liquid compound practically of the same nature as the solid paraffin with the same properties and adaptability as regards waterproofing. Both kinds of paraffin are extensively used as surface coatings for stone, brick, and concrete, making the latter both dampproof and waterproof. Stones are often impregnated with paraffin to prevent erosion when exposed to the elements.

Sand. Nearly all sand is more or less pure quartz grains which will all pass through a $\frac{1}{4}$-inch sieve with not more than 8 per cent passing a No. 100 sieve. The sand best suited for making impervious concrete is coarse, sharp and silicious, containing not more than 2 per cent of mica, loam, dirt or clay, separately or combined. For good results as regards impermeability it should be graded about as follows:

No. of Sieve.	Limit of Fineness (Per Cent Passing).	Limit of Coarseness (Per Cent Passing).
4	100	95
8	95	85
16	75	40
30	50	20
50	30	2
100	6	0

See Appendix 1 for explanation of mechanical analysis curves for grading concrete aggregates.

Steel Plate. Steel plate used for tunnel linings is made by the open-hearth process.* In tunnel construction, it often acts both as a structural component of the tunnel and its waterproof lining. To reduce leakage through the joints to a minimum after erection, the plates should be perfectly fitted and riveted through properly reamed holes. Edges of all plates must be planed and calked inside and out. When steel plates are used for tanks and sometimes even for structural purposes it is also necessary to make the joints watertight. A very good scheme is to introduce a strip of treated felt a little wider than the pitch of rivets between the joints. The heat and compression of the rivets bring out the cementing properties of the joint filler.

Stone Aggregate. Stone used for concrete consists mainly of trap, limestone, marble, granite, syenite and gneiss. The composi-

* The Journal of the Municipal Engineers of the City of New York, Vol. 1, No. 6, p. 16, December 1, 1915.

tion and characteristics of these stones are more or less a matter of common knowledge, and a discussion of their properties would encumber this article. What is true of gravel, as regards the making of dense concrete, is approximately true of any of these stones for the same use. See Appendix 1 for explanation of mechanical analysis curves for grading concrete aggregates.

Tar. (*A*) Coal tar: Coal tar is a black, more or less viscid, oily liquid, a mixture of hydrocarbon distillates resulting from the destructive distillation of soft coal in the production of illuminating gas. It was first recovered in 1771 by Stauf, a German chemist. There are various kinds of tars, depending on the type of oven and kind of coal used. The chief difference in these tars is the varying percentage of free carbon present. By fractional distillation, that is, by the removal of certain of the more volatile oils present in the crude tar, it can be carried to a point at which the residuum in the still has acquired any desired consistency at normal temperature. This semi-solid or solid residual product is called pitch. The best waterproofing pitches are obtained from straight-run (unadulterated) coal tar produced at reasonably high temperatures, though for roofing purposes pitch is also made of oil and water-gas tars. Coal tar is used as a dampproof and protective paint and for saturating waterproofing felts.

(*B*) Water-gas tar: Water-gas tar is a mixture of hydrocarbon distillates, produced by cracking oil vapors at high temperatures in the manufacture of carbureted water gas. Crude water-gas tar is a thin, oily liquid having a specific gravity lying usually between 1 and 1.10. As a rule it contains a considerable quantity of water, which is, however, largely removed by mechanical devices before the tar is placed upon the market. The composition of water-gas tar varies with the character of the oil which is carbureted and varying conditions affecting the process. It always shows a low percentage of free carbon, usually less than 2 per cent, and is more easily decomposed and more affected by water than coal tar. In crude form it is used as a road dust-palliative. When reduced to the proper consistency by distillation it is used as a road binder, in the manufacture of a few minor waterproofing materials and for treating a special grade of waterproofing felt and fabric.

Water. The term " water " is ordinarily understood to mean the liquid composed of two parts of hydrogen and one part of oxygen, chemically combined. But to the engineer the " H_2O " of the water is of less concern than the suspended and dissolved matter in the water in general use. Its abundance is too often taken as proof positive

of its purity. But reasonably pure, clean, fresh water is not always available. Still these qualities and the amount used in making a specific mixture of concrete are as essential in the making of good concrete as good cement, sand and stone. Water for good concrete should be free of every form of pollution, excessive amounts of acids and alkalies and all forms of organic matter. Salt water should never be used in making reinforced concrete. The presence of any of these foreign ingredients affects the cement more or less and reduces the density and consequently the impermeability of the concrete. The functions of water in concrete are: (*a*) to form, with the cement, the binding material uniting the sand and stone; this is accomplished automatically by dissolving the cement, forming acids from anhydrides, and bringing these new acids and dissolved bases of cement into intimate contact for chemical reaction; (*b*) to flux the cementing substances over the surfaces of the aggregate so as to insure extensive adhesion; (*c*) to act as a lubricant for the aggregate. These are completely operative only if the water is reasonably pure.

Some of the materials above considered are, of course, used for many other purposes than waterproofing, but such enumeration would be foreign to this subject.

The many secret compounds referred to throughout the book consist mostly of (*a*) chemical salts and limes; (*b*) solutions of various petroleums and linseed oil, and (*c*) mixtures of powdered metal, slag and Portland cement.

Analyses of many patented waterproofing materials by Government and private chemists prove some of them of questionable merit, and some of but temporary value, imparting impermeability to concrete but for a short time only, and with some of these compounds unfortunately, their secrecy more often overbalances their efficacy.

CHAPTER VI

WATERPROOFING IMPLEMENTS AND MACHINERY

Applicability of Tools and Machinery for Waterproofing. The tools, implements and machinery employed in the waterproofing industry are somewhat connected with the asphalt pavement industry with which most engineers and contractors are more or less familiar. Some tools are used in common and some implements are easily modified to suit either industry. The tools and implements are usually of simple construction, and some are often home-made,

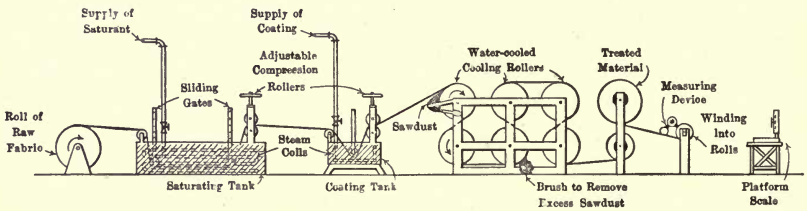


FIG. 63.—Diagrammatic View Showing Process of Saturating and Coating Burlap or Cotton Fabric with Bitumen.

though all are supplied by manufacturers who make a specialty of this trade; but the machinery, such as is used for saturating and treating waterproofing felts and fabrics, is more complicated (see Fig. 63), and requires design. The manipulation of most of these tools and machines, however, is simple and does not require particularly skilled labor, either in the field or factory. There are variations and even distinctly different forms of these articles in the market, but those described herein are mostly standard or fast becoming so.

VARIETIES OF MASTIC MIXERS

Spherical Mastic-mixing Kettle. The mastic-mixing kettle shown in Fig. 64 is very extensively used by general waterproofers. The pot in the figure fits into the jacket, or mantle. The kettle and mantle are made of steel plate, with top and bottom bands.

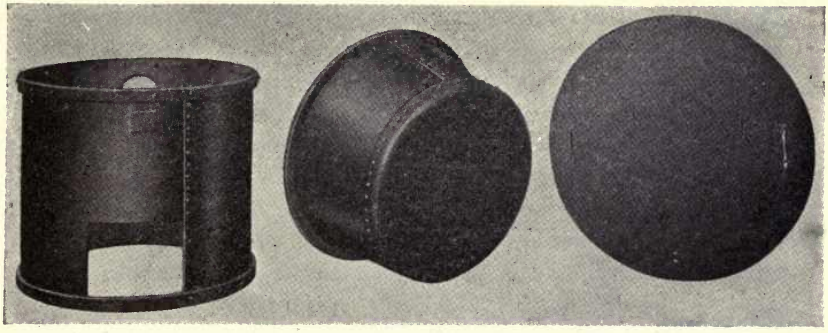


FIG. 64.—Asphalt or Mastic Heating Kettle.

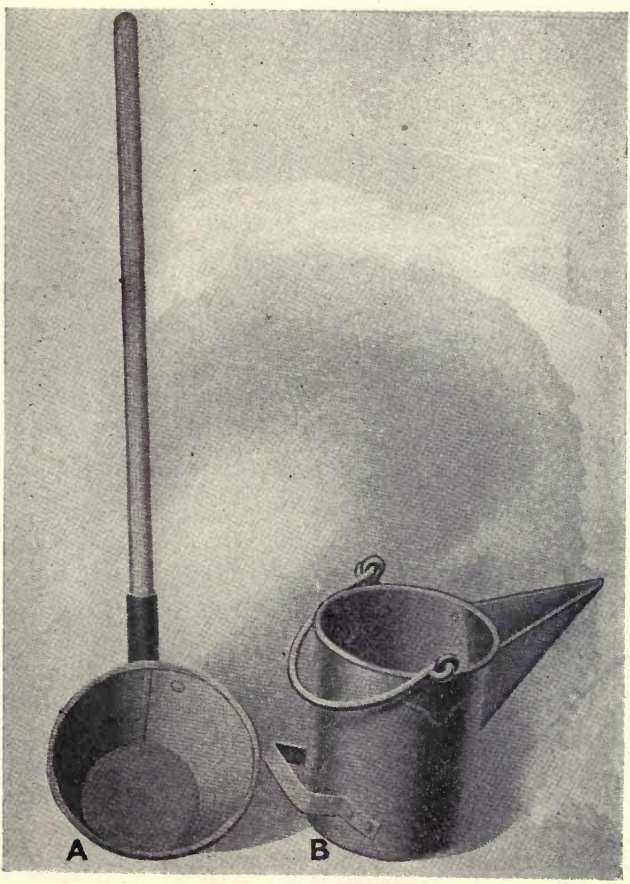


FIG. 65.—Typical Dipper and Pouring Pail Used in Waterproofing with Asphalt or Tar.

The bottom of the kettle is riveted but easily removable when burnt and removal is necessary. The dimensions of the kettle are as follows: Kettle, 38 inches diameter at top, $\frac{3}{16}$-inch plate, 21 inches deep; bottom, $\frac{3}{8}$ inch thick. Mantle, 40 inches diameter, 36 inches high, of $\frac{3}{16}$-inch plate. Kettles of 50 gallons capacity are the most generally used. Through the opening in the mantle a wood fire is built under the kettle in which the bitumen gradually melts. While in a hot and molten condition, the bitumen is poured into small kettles or pouring pails by means of dippers, both of which are shown in Fig. 65.

Cylindrical Mastic-mixing Kettle. Cylindrical mastic-mixing kettles are well adapted for making mastic because every part of

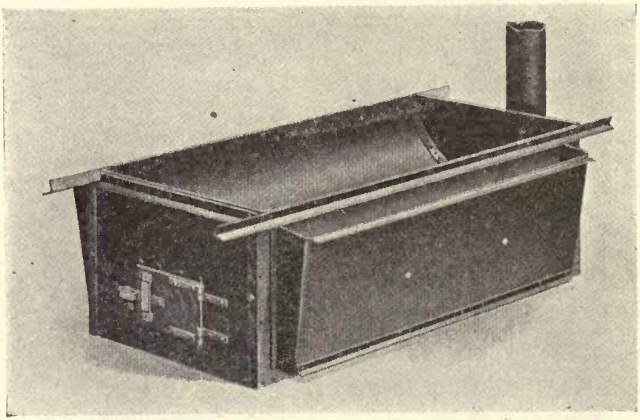


FIG. 66.—Cylindrical Mastic Kettle.

its interior surface is accessible to the kettleman. This is all the more so because straight-edged stirrers are the most generally used, regardless of the type of kettle. This type of kettle is made in several sizes, of $\frac{3}{8}$-inch metal, with sand and gravel-drying pockets on either side and a fire space underneath the cylinder, as shown in Fig. 66. The kettle rests directly on the ground and can readily be carried away by four men.

Mechanical Mastic Mixer.* The mechanical mixer shown in Fig. 67 is constructed so that it can be drawn without any difficulty to any location or to any part of the work. It consists of a steel rotary drum which revolves in a fire brick-lined steel casing set on a

* Originated by the Guelich Paving Process Co. of Philadelphia, Pa., and patented November, 1911.

rectangular I-beam truck; the drum proper is 5 feet long and 34 inches in diameter. The drum heads revolve about a horizontal axis, while the barrel of the drum has a 6-inch eccentricity on each

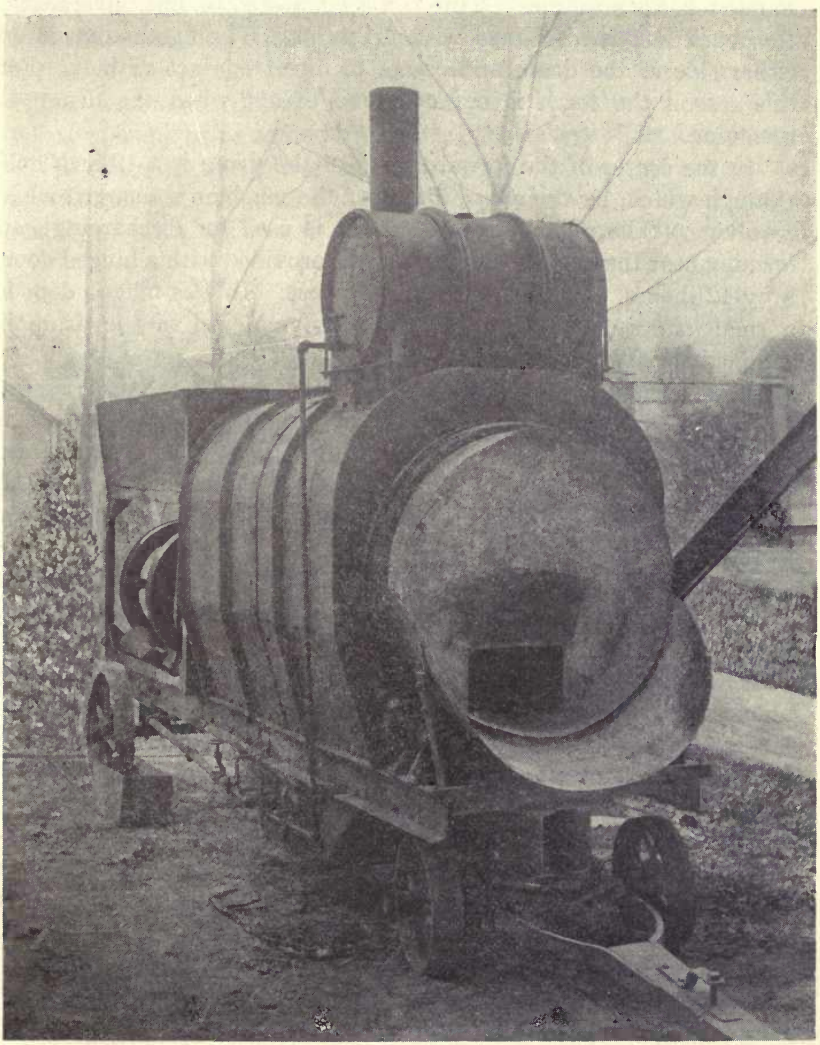


FIG. 67.—Mechanical Mastic Mixer, Rear View. (Patented in U. S. A., November, 1911.)

end. The drum is perfectly smooth, being butt jointed. Within the drum is a series of flat, rectangular paddles set at an angle of 45 degrees with the axis. Attached to the forward end of the drum

is a curved rack which meshes with a gear driven by a direct-connected gasoline engine also at this end. To the engine is connected an air blower which supplies the air for vaporizing the fuel oil, the heat source for this machine. A fire box is connected to, but underneath, the truck and is also lined with fire brick. The flame spreads on either side of the drum and comes in direct contact with it. For this reason the torch is never lighted except when the drum is revolving.

In the center of the forward head of the drum is a 10-inch hole through which, by the aid of a hopper the machine is charged while revolving. The rear end of the drum is used for discharging; an opening near the edge of the drum head, provided with a hinged door, 8 by 12 inches, being used for this purpose. In this hinged door is a small shuttle door through which the material in the drum is sampled while being cooked.

In starting the machine the mastic constituents, that is, the sand, grit, limestone dust and cement, are thrown into the drum through the hopper and at the same time pieces of asphalt are also thrown in so as to mix more thoroughly with the aggregate. All materials must be weighed, but none of them needs preheating preparatory to mixing.

The total weight of the machine, when empty, is about 3 tons. Its dimensions are: height, about 5 feet; width, 4 feet; and length, 8 feet.

The capacity of the machine is about 1000 pounds of mastic in about thirty-five minutes. It requires one engine runner and two laborers to tend this machine, and between 1000 and 1400 square feet of 1-inch floor mastic or sheet mastic for waterproofing purposes can be produced by it per working day.

The drum must be cleaned after each day's work. This is accomplished by throwing some grit into it, allowing it to revolve for a few minutes while the torch is burning, and drawing off the product gradually until the drum is empty.

Varieties of Heating Kettles

Steam-jacketed Heating and Mixing Kettle. Steam-jacketed kettles for heating bituminous materials, or mixing bituminous mastic, are used in many asphalt plants throughout the country; but these are invariably of very large sizes, ranging between 200 and 500 gallons capacity, and also of various forms.

Small kettles of this type, say between 50 and 100 gallons capa-

city, could be employed on engineering work where large quantities of these materials are used for floor paving or waterproofing purposes. While this has never been tried, so far as the author is aware, nevertheless he feels confident that it would result in marked economy were these kettles substituted, where possible for the fire-heated kettles of the present day. This would follow for several reasons. It is a demonstrated fact that coal-tar pitch is robbed of some of its volatile oils by being heated over a fire preparatory to its use, because of the concentration of heat and the natural lightness of some of the constituent oils. Asphalt likewise suffers deterioration, though not as readily as pitch. The cost of handling fire-wood, plus the cost of at

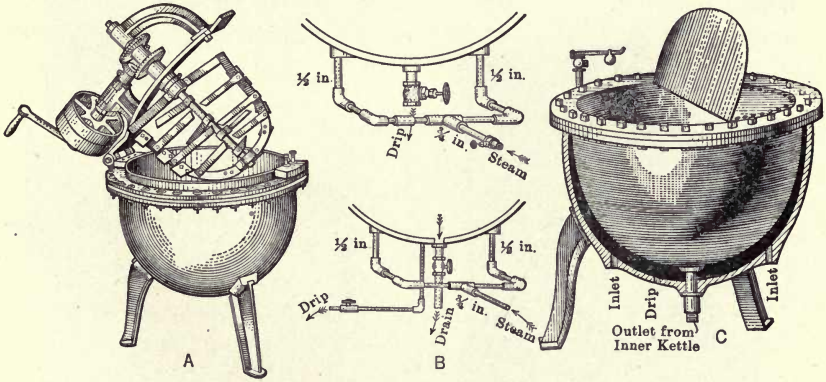


FIG. 68.—Double-jacketed, Steam-heated Mastic Mixing and Asphalt Heating Kettle.

A. Kettle with mastic mixing device.
B. Pipe connection for kettle.
C. Asphalt heating kettle, showing arrangement of jackets

least three hours' overtime every day for a man to start the fires under the kettles at early dawn; the lack of a uniform product so often the result of making hand-mixed mastic; the fact that all work of any magnitude at all, has a steam plant working practically all the time with considerable waste of steam for lack of use; all these facts taken together and the frequent need for replacing the burnt fire-heated kettles make a cost item to be considered in comparison, and would show it to be decidedly advantageous and economical to use the steam-jacketed kettles.

Various types of steam-jacketed kettles are on the market and used for various purposes such as making chemicals, paper, glues, etc. The type suitable for heating bitumen is shown in Fig. 68, *C*. This is made of plain iron with or without a cover and with or without

an outlet from the inner kettle. The cost of this kettle depends on the capacity: 45 gallons costing about $66.00; 65 gallons $81.00; 100 gallons about $121.00. Fig. 68, *A*, shows the kettle adapted to making mastic mechanically by the addition of a double mixer, gear, shaft and hand crank hinged arbor. The cost of this type of mixer also depends on the capacity, namely, 45 gallons about $125.00; 65 gallons about $150.00 and 1000 gallons about $207.00. At *B* is shown the pipe connections for each style of kettle.

The steam pressure required for raising the cold materials in these kettles to their proper temperature is about 100 pounds per square inch applied for about one hour.

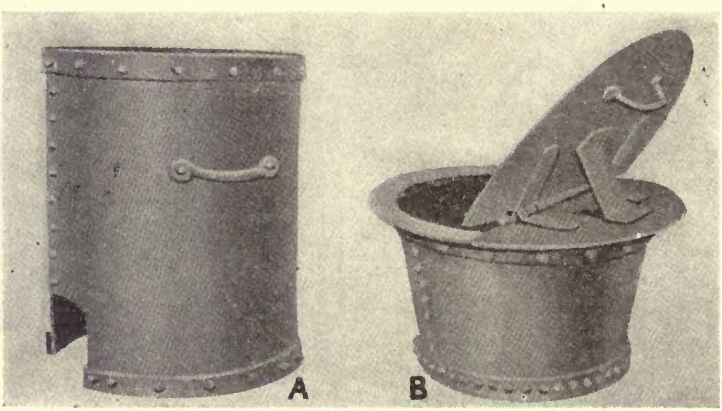


FIG. 69.—Roofer's Kettle, Used for Heating Bitumen and Mastic.
A. Mantle. *B*. Kettle.

A modified steam-jacketed kettle can be made out of the present fire-heated kettles by lining them with steam coils suspended from the edges.

Round Roofer's Kettle. The kettle shown in Fig. 69 is used mostly by roofers in exactly the same manner as the asphalt and heating mastic kettles. This kettle is strongly constructed, handy for small jobs and for patching purposes. These roofer's kettles are generally built and used in sizes of 20, 30 and 50 gallons capacity.

Rectangular Roofer's Kettle. The roofer's kettle shown in Fig. 70 is made rectangular in form and in capacities of 50, 100 and 150 gallons. They are built of No. 14 sheet steel, riveted and braced in all corners with angle iron. The tank is made with bottom semi-cylindrical in form, separate from fire box, thus facilitating repairs in replacing burnt bottoms. The furnace is reinforced on the inside

by an extra thickness of No. 14 steel to resist the heat. The kettles are usually provided with four carrying handles attached to the side sheets as shown.

Portable Heating Kettle (Drag Type). In Fig. 71 is shown a large portable heating kettle mainly used by roofers. It is very serviceable, especially the davit, which greatly facilitates handling barrels. In warm weather the heat from the melted bitumen in the kettle is sufficient to make the bitumen flow from the bung of the barrel, which is placed so that it opens downward. This keeps the barrel intact which may then be used again. The kettle may be had in capacities of 150 to 500 gallons.

Portable Heating Kettle (Wagon Type). The portable heater shown in Fig. 72 is used chiefly by roofers. This type of heater is

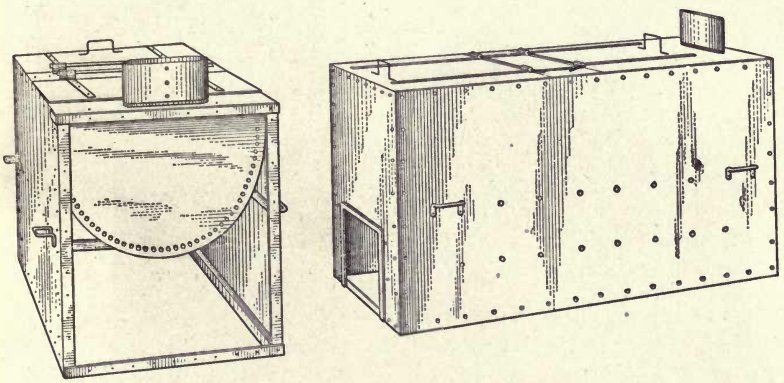


FIG. 70.—Stationary Roofer's Kettle. (End View has Outside Jacket Removed.)

intended for long hauls and small jobs. The bitumen can be heated while being hauled to the work. In places where the municipal authorities will not allow a thoroughfare to be blockaded by stationary kettles, this is found a desirable outfit. The space back of the driver's seat is arranged for holding wood, having sufficient space for about two days' supply. There is also a rack for carrying pails, dippers, mops, etc. The heating tank is provided with a hinged cover. This type of heater usually comes in sizes of 100 to 150 gallons capacity.

Portable Heating Kettle (Hand Cart Type). The portable kettle illustrated in Fig. 73 is much used by roofers and waterproofers, particularly the latter, because it is made in as small capacities as desired. By the use of this type of small portable heating kettles, the stationary mixing kettles can be almost any distance from the

work, and the bitumen, or mastic, can, by means of them, be transported hot from the heating or mixing kettles to the place of application. The smaller portable kettles need no projecting chimneys.

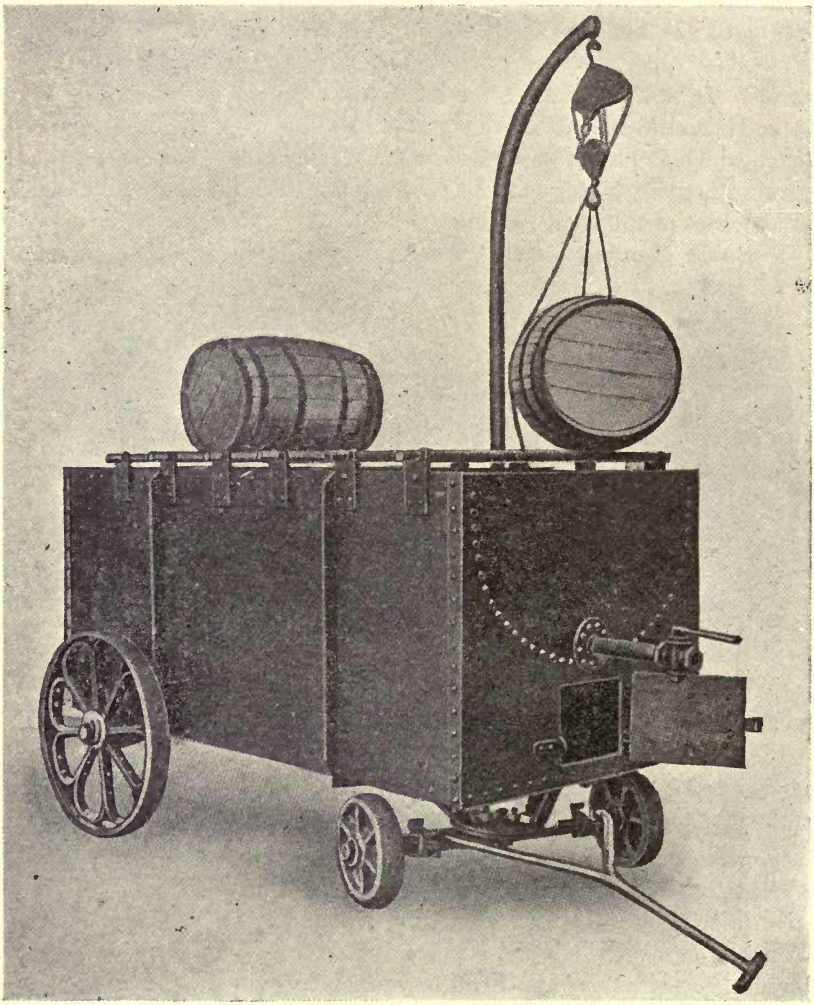


FIG. 71.—Portable Asphalt and Tar-heating Kettle with Davit Attachment.

The furnace is equipped with sheet steel bottom, of No. 12 gauge, and is tongue-riveted to the tank. It has a wrought-iron handle provided with a foot rest in front, and a discharge pipe from the tank in the rear.

Combination Tar and Gravel Heater. A tar and gravel heater, similar in construction to but usually larger than the portable

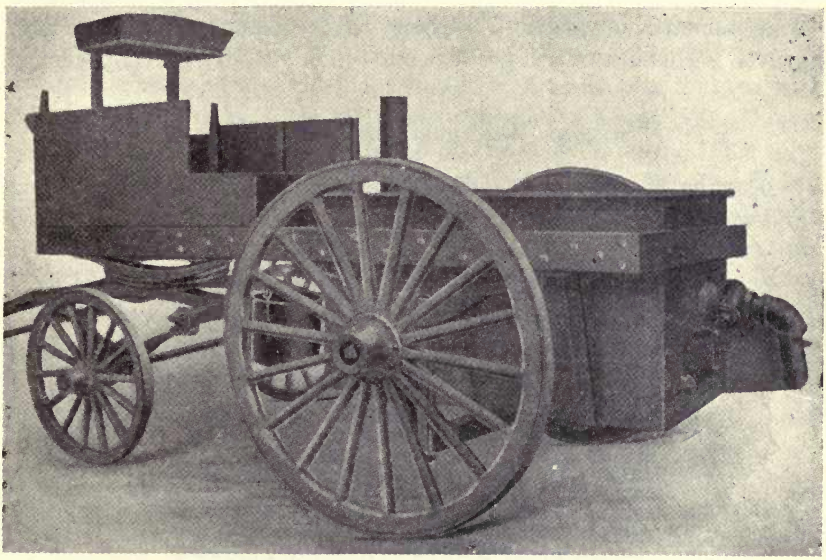


FIG. 72.—Wagon Type of Tar and Asphalt Heater.

kettle shown in Fig. 73 is used by roofers and general waterproofers alike. On top of the heater are two doors, one enclosing a round-

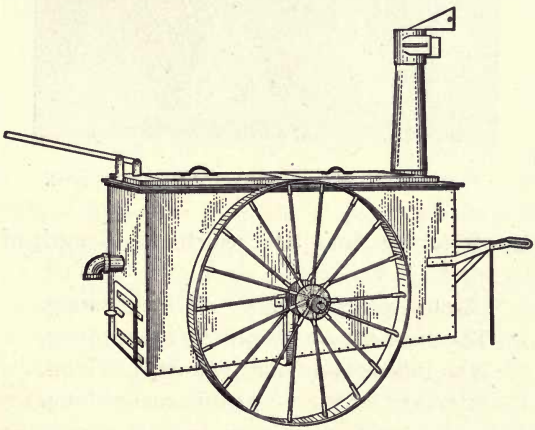


FIG. 73.—Hand-portable Type of Tar, Asphalt, and Mastic-heating Kettle.

bottom tank in which the bitumen is heated, and the other an inclined container for the sand or gravel which is drawn out as needed from an

upper door in the end. A lower door encloses the fire box. In the rear of the heater is a spout for drawing the bitumen. The heater can be transported from place to place by attaching it to a wagon. The standard kettle has a capacity of 70 gallons of bitumen and gravel. This heater will produce one ton of hot, dry gravel per hour.

Sundry Waterproofing Implements

Roofing Mops. The mops shown in Fig. 74 are used for roofing and waterproofing alike. They are made of a cotton warp, attached

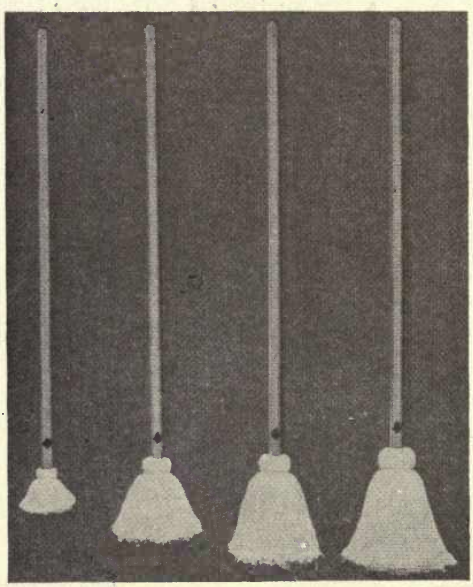


Fig. 74.—Roofing and Waterproofing Mops.

to wooden handles 4 feet long, the weight and length of warp being as follows:

3-ounce cotton warp, $5\frac{1}{2}$ inches long.
12-ounce cotton warp, $9\frac{1}{2}$ inches long.
20-ounce cotton warp, 12 inches long.
32-ounce cotton warp, 15 inches long.

The two smallest are used chiefly for roofing, the two longest, chiefly for general waterproofing.

The general practice is to buy bales of cotton warp, and make the mops on the work, as needed.

Mastic Stirrers. Fig. 75, *A*, illustrates an efficient type of mastic stirrer for round-bottom kettles. Other types consist of a long-handled paddle whose end is shaped like an oar; or an iron rod terminating in a flat triangle as shown in Fig. 75, *B*. This is best suited to the cylindrical type of mixing kettle. Another type of stirrer is made of a coffin-shaped piece of sheet iron perforated with ½-inch holes, and securely fastened to the end of a long pole. Sometimes a strong flat stick, picked up on the work, is used. This type, however, as well as the oar or coffin-shaped stirrers, are not efficient tools. A modification of the stirrer shown in Fig. 75, *A*, consists in making the frame square, but as the majority of kettles used are round-bottomed, this also does not make an efficient stirrer. In the stirrer shown in the figure the handle is made of wood inserted into an iron rod, which terminates in a ring, the hole of which is

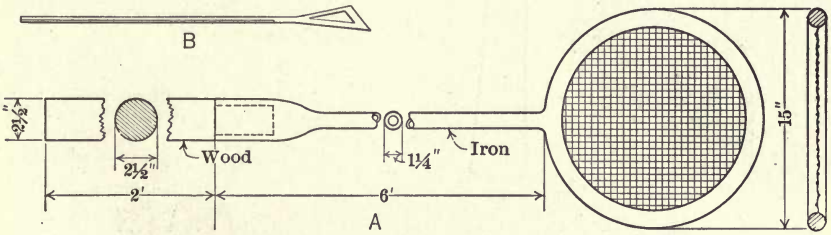


FIG. 75.

A. Paddle Type of Mastic Stirrer, (½-inch Wire Mesh).
B. Stirring Rod.

occupied by a ⅛- or ¼-inch iron-wire screen of ½-inch mesh securely fastened to the ring.

Dipper and Pouring Pail. The dipper and pouring pail shown in Fig. 65 are usually made of galvanized sheet iron, or other sheet metal, in several sizes and capacities, the most common of which being the 3-gallon type. They are both reinforced with a heavy wire band at the top. The base of the ferrule of the best dippers is riveted to the bottom. The dippers have wooden handles from 6 to 8 feet long. The type of pouring pail shown in Fig. 76, *A*, may serve also as a melting pot and when so used, is placed in a suitable portable furnace, like a salamander. The seams in this kettle are rolled and the top is divided and hinged across the middle.

Asphalt Smoother. The asphalt smoothers shown in Fig. 76, *B*, have but a limited use in waterproofing work. They are, however, very efficient for the limited purpose for which they are applicable,

especially the very small ones, whose base is about 3 by 4 inches (curved like the larger smoothers) with short iron handles. They are heated and used to soften the exposed ends and laps of bituminous membranes to insure a good waterproof joint between old and new

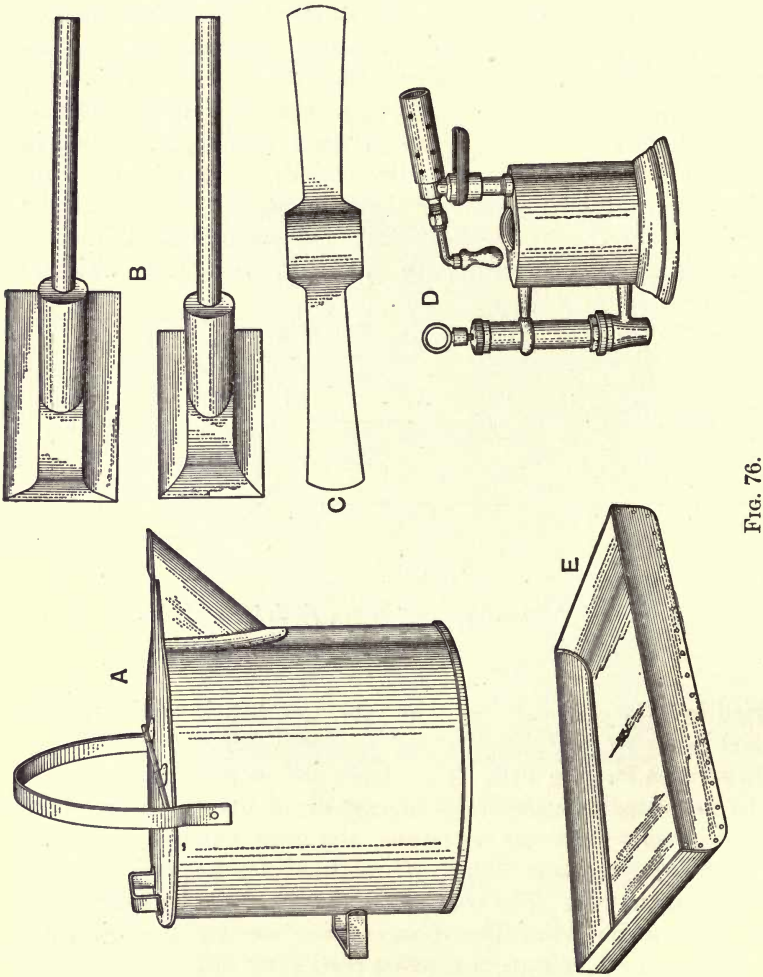


FIG. 76.

A. Pouring Pail, also Usable as a Melting Pot for Bitumen.
B. Cast-iron Asphalt Smoothers.
C. Asphalt Cutter (Double-edged).
D. Gasoline Torch (Quart Size).
E. Gravel and Sand Heating Pan.

work. The manner of using the smoother for waterproofing is the same as in paving work. The larger smoothers are made of cast iron in two sizes, their faces being ground smooth and to a curve. They are provided with handles made of $1\frac{1}{4}$-inch pipe, bent at the upper end, and welded to a steel stub cast in the head of the smoother.

Gasoline Torch. The torch shown in Fig. 76, *D*, is the one most generally used for heating laps and small surfaces of old waterproofing of the membrane and surface coating types. It is sometimes also used for heating concrete in the mixer, in freezing weather, where it is very effective, and helpful in producing good concrete in cold weather. This torch produces a blue flame of great heat efficiency. The shipping weight of this type of torch is about $4\frac{1}{2}$ pounds.

FIG. 77.—Method of Drying and Sieving Sand; Typical Arrangement of Fire-heated Kettles for Making Mastic. (Note Yoke for Carrying Pails of Hot Pitch or Mastic.)

Asphalt Cutter. In Fig. 76, *C*, is shown an asphalt cutter widely used where asphalt or hard tar products are employed in construction. With it, wooden barrels and tin drums, in both of which the pitch and asphalt are received on the work, are readily cut up, exposing the materials. These are in turn cut up into small pieces for easy handling. The cutters are made of tool steel, with tempered edges, thus giving long service before the tool has to be repaired. The length of cutter from edge to edge is $20\frac{1}{2}$ inches; width of edge 3 inches; shipping weight of double-edge cutter is 10 pounds.

Gravel Heating Pan. The gravel heating pan shown in Fig. 76, *E*, is much used by roofers and general waterproofers. In service it is usually supported by several bricks under each corner

FIG. 78.—Method of Drying, Heating, and Sieving Sand in Large Quantities.

permitting a wood fire to be built underneath. The sand or gravel is spread over the pan, and dried or heated as desired. These pans are made of soft steel with riveted sides. The most generally used size is 106 inches long, 42 inches wide and 8 inches deep.

Sand and Gravel Heating Pipe. The pipes shown lying on the ground in Fig. 77 are sheet metal, but more usually old, discarded, cast-iron water pipes, over $1\frac{1}{2}$ feet in diameter. They are used very extensively by waterproofers for drying and heating sand and gravel in large quantities. Where possible, the sand or gravel is dumped directly on the pipes as shown, otherwise these materials are shoveled on until a pile, 2 or 3 feet high, rests on them. A wood fire is built inside of these pipes, in which a natural draft is always present. When the sand is sufficiently heated, it is usually screened (see man with shovel at wheelbarrow) before being used. Fig. 78 shows an improvised pipe furnace for drying, heating and screening sand in large quantities.

Salamander. The salamander shown in Fig. 79 is used for drying bricks which are intended for brick-in-mastic waterproofing, and also for heating enclosed areas to be waterproofed in cold weather. Salamanders are usually made of $\frac{1}{8}$- or $\frac{3}{16}$-inch steel plate and equipped with heavy cast-iron gratings. They come in several sizes, the most common being 17 inches in diameter by 20 inches high and 20 inches in diameter by 24 inches high.

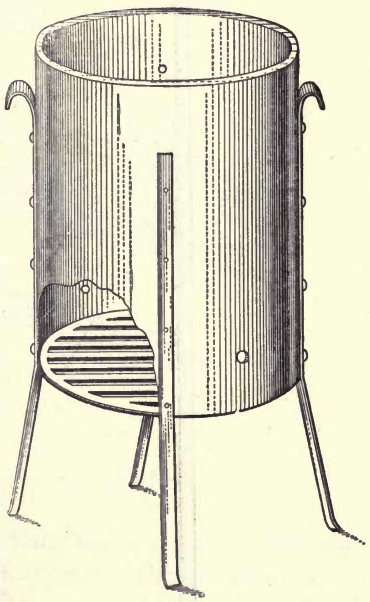


FIG. 79.—Iron Salamander Used for Drying and Heating Bricks.

Wheel Barrow. A steel-tray wheel barrow, besides serving its obvious purpose, is very commonly used for volume measurements of the mineral ingredients entering into the making of mastic for waterproofing. Such a wheel barrow is usually constructed of Nos. 16 to 12 gauge steel, and in capacities of $2\frac{1}{2}$ to 6 cubic feet.

Concrete Tampers. The tampers shown in Fig. 80, *A*, *B* and *C*, are designed to insure a compact concrete mass. The tamping process is really a slicing and cutting process for the purpose of letting air bubbles out of the concrete. Ordinary tamping is done by a form of tamper shown in Fig. 80, *B*. For facing work, the gridiron tamper in Fig. 80, *A*, gives excellent results. The tamper shown at *C* is constructed with two spacings.

Trowels and Floats. Fig. 81, *A*, represents the usual form of trowel used for pointing between copings, or flashings and walls, etc. Fig. 81, *B*, represents the usual form of trowel used in applying and smoothing waterproofed plaster and mortar. Fig. 81, *C*, is a wooden spreader or float generally used for spreading and floating bituminous-mastic floors, sheet mastic waterproofing, etc. It is about 1

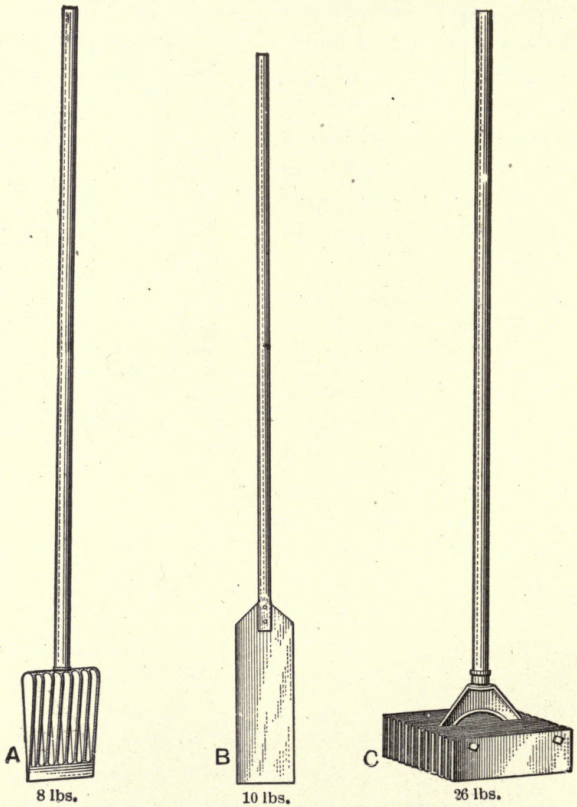


FIG. 80.—Concrete Tampers.

foot long, 4 inches wide and 2 inches thick, with smooth and true faces all around. In using the float its beveled edge is held forward and applied in a somewhat diagonal direction while pressure is brought to bear on the handle. It is not possible to secure the same fine, finished surface on these materials with an iron trowel or smoother.

Cores for Felt and Fabric Rolls. Waterproofing felt and fabric is put up in rolls so as to make handling easy (see Fig. 120). In ship-

ping, hauling and storing, these rolls would be badly crushed, warped, bent and wrinkled but for the solid core on which they are usually wound. The cores are sometimes made of paste-board roll and slat crates but most often of solid square or round sticks. Water-

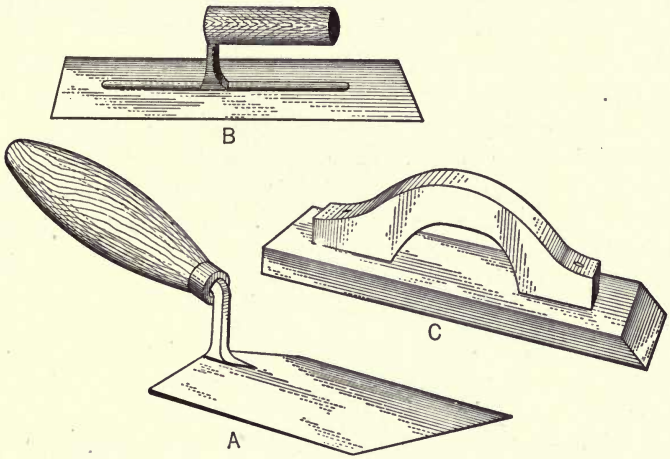


FIG. 81.

A. Mastic trowel.
B. Mortar Trowel.
C. Wood Spreader or Float for Mastic Floors.

proofing felts are often rolled up without any cores, but waterproofing fabric can never be handled without cores. The various types employed are illustrated in Fig. 82.

Mechanical Brick Heater. A practical and economical method of drying and heating bricks is by the use of an iron furnace, or

FIG. 82.—Types of Cores upon which Felt and Fabric is Rolled for Shipping.

heater.* This heater consists of a rectangular sheet-iron box about 4 by 4 feet and 8 feet high. On opposite sides and at different elevations it has rectangular openings 10 or 12 inches high and 4 feet wide. To the bottom of these openings are attached hinged doors.

* Designed and used by the New York Roofing Co.

Gratings inclined about 45 degrees connect with the bottoms of the door openings. A low, flat, iron, box-like salamander placed on the ground under the lowest grating completes the equipment. The process of heating the bricks is commenced by kindling a charcoal fire in the salamander, and placing bricks on the first grating through the most elevated door connected therewith, the lower one remaining closed. Then bricks are placed on the second grating and finally on the third grating. By the time this is done the bricks on the first grating are sufficiently dry and warm and may be dumped from the heater into a wheel barrow or other conveyance by opening the door on the lower level. Then the second and third doors above are opened in succession, allowing the bricks to fall out automatically. With this heater, 14,000 to 20,000 bricks per day can be dried and heated to quite a high temperature and without soot.

The Cement Gun

Fig. 83 illustrates a modern type of cement gun. A sectional view is shown in Fig. 84. This type is built to withstand air-pressure up to 60 pounds per square inch. The following description will aid in understanding its operation:

The tanks marked in the figure as 4 and 5 are steel sheet, welded on both sides and riveted to flanges as shown. The tank is hinged to the cast-iron base to permit access to the interior for cleaning. The cone valves 3 and the feed wheel 6 are of cast iron with a smooth finish. The air motor 9 drives the feed wheel through a worm and worm gear. The dry materials, mixed in the proper proportions, are placed in both tanks through the open valves, before any air is turned on. Then the upper cone valve 3 is closed by means of lever 2 and compressed air is admitted through cock *A*, which holds the cone valve in place. Cock *B* is then opened, admitting air through a gooseneck and the outlet valve 8. Cock *C* is then opened which makes the feed wheel 6 revolve, and the material in each pocket of same, as it registers with the gooseneck, is blown out through valve 8, into the material hose attached thereto, to the nozzle where the water from a separate base is added.

To recharge the machine it is not necessary to stop it, as the lower cone valve 3 is held in the position shown when the air in the upper tank is exhausted. The upper cone valve then opens and a new charge is put into the machine. The operation of this machine must be continuous while the mortar is being applied.

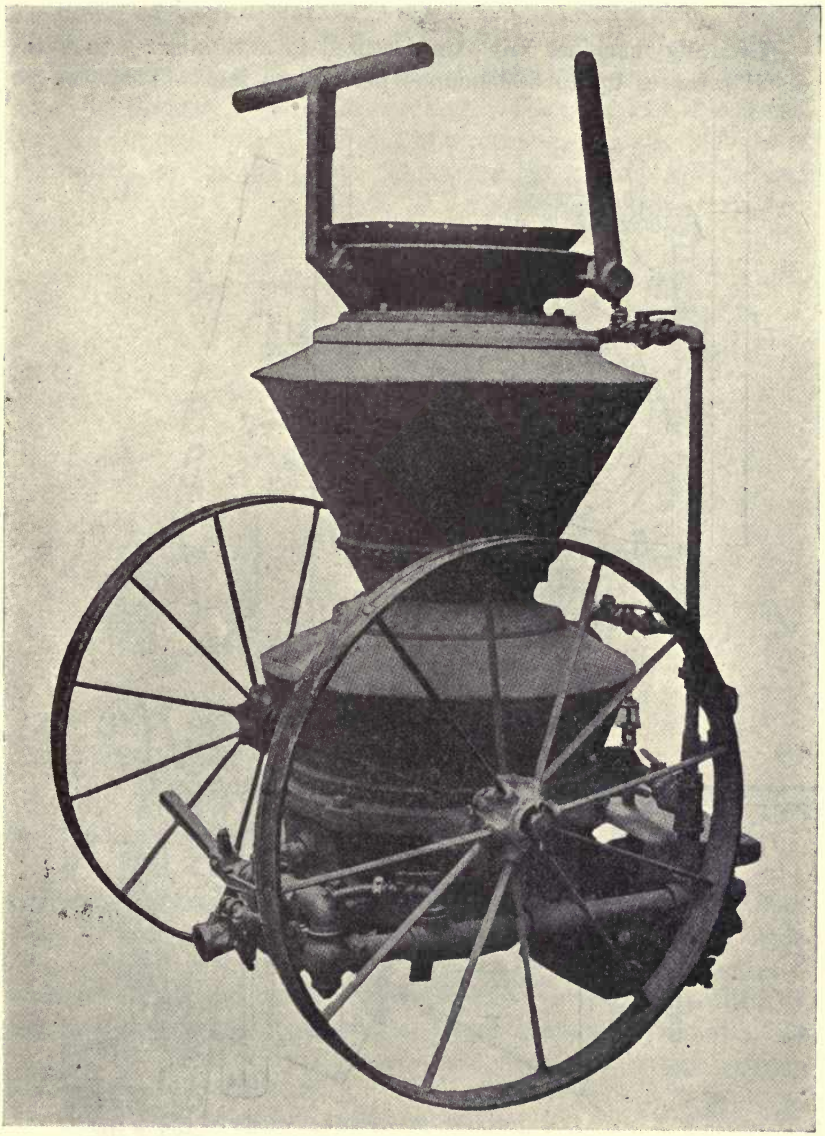
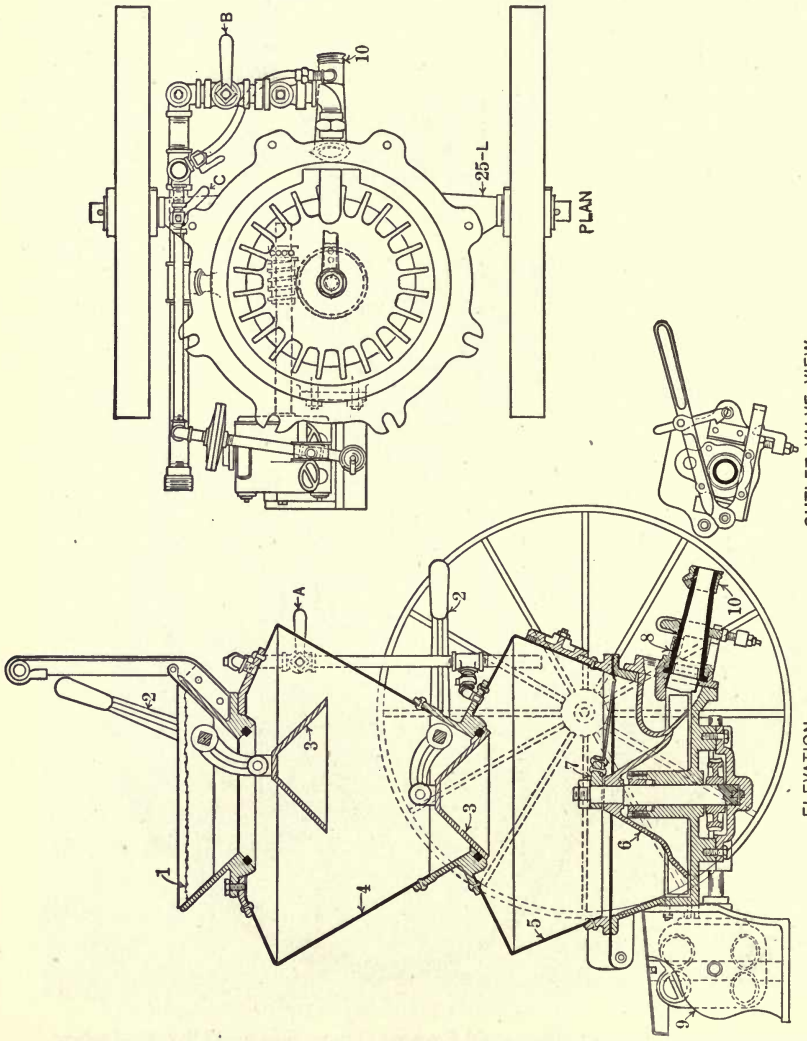


FIG. 83.—Cement Gun. (Height, 69 Inches; Floor Space, 42 by 44 Inches; Weight, 1350 lb.)

The Grouting Machine

Grouting machines are manufactured in several sizes to withstand presures up to 600 pounds per square inch. They can be



1. Screen.
2. Cone valve levers.
3. Cone valves.
4. Upper tank.
5. Lower tank.
6. Feed wheel.
7. Agitator.
8. Outlet valve.
9. Air motor.
10. Gun hose coupling.

Fig. 84.—Cross-section of Cement Gun.

made to stir the grout mechanically, or by compressed air. Fig. 85 shows a small-sized patented grout mixer designed for mixing grout by compressed air only. The space occupied by such a machine is

about 3 by 3 feet and 4 feet high. The average batch capacity is about 4 cubic feet.

Referring to its operation, *B* is the compressed air inlet. Valves *C*, *D*, and *F* are closed and door *A* opened. The sand and cement are charged through the door *A*, and a measured quantity of water is admitted through *A* by means of a hose. Then the door *A* is closed. Valve *D* is now opened, allowing the compressed air to blow in at the bottom to mix the grout. This keeps the mixture agitated and

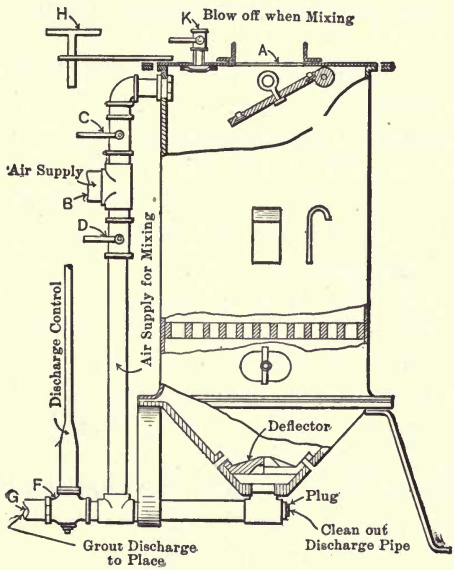


FIG. 85.—Section of Ransome-Caniff Grout Mixer. (Patented.)

prevents the sand and cement setting into and choking the outlet, pipe *G*. During this operation, the blowoff valve *K* must be open. When the batch is mixed, valves *K* and *D* are closed, and valve *C* opened. When the batch is to be ejected, valve *F*, controlled by handle *H*, is opened and the grout discharged through a hose attached to outlet *G*. Then valves *C* and *F* are closed, the excess pressure allowed to blow off through valve *K*, when the door *A* drops open, and the machine is again ready to be charged.

CHAPTER VII

TECHNICAL AND PRACTICAL TESTS ON WATERPROOFING

Necessity of Testing Waterproofing Materials. Testing of waterproofing materials is necessary to insure good and uniform products. Representative specimens of materials to be used should be tested in the laboratory for comparison with specified requirements. Analysis should be made when any doubt exists regarding the true nature of the material. This is especially true of tar and bituminous compounds and proprietary products, as has, no doubt, become evident. Some practical field tests may reveal certain undesirable qualities, but laboratory tests can often be relied upon to reveal more, and should not be neglected.

To know the properties of materials is not more essential than knowing how to test for these properties, at least in a practical way. In the light of present-day knowledge of waterproofing materials, it is necessary for the engineer to be acquainted with methods of testing and to be able to correctly interpret results of tests. Of equal importance to the tester is a knowledge of the significance of the tests called for in specifications. For this, however, both technical knowledge and experience are necessary.

In this chaper technical tests on pitch and asphalt are briefly described and their significance explained; also tests and results on the impermeability of plain and waterproofed concrete and cement mortars, and certain practical tests related to general waterproofing are described. The results of some of the tests described herein will make evident certain statements of facts made in other chapters. Particular attention is directed to the many practical tests as showing the logical way of aiding the engineer's judgment in arriving at conclusions in regard to the adaptability of some materials for unusual purposes. Waterproofing involves comparatively little theory, which, perhaps, explains its slow progress, and its continuance as an art rather than as an exact science.

Significance and Description of Technical Tests on Bitumens

The bitumens form the most important and widely used materials for waterproofing. It will be well, therefore, to describe some of the laboratory tests made on this class of materials in more detail than the others.

The following list of tests includes all those of more or less value in determining and recording the characteristics of tar and bituminous materials used for waterproofing purposes:

Coal-tar Pitch. Specific gravity at 60 deg. Fahr. (15.5 deg. Cent.) or 77 deg. Fahr. (25 deg. Cent.).

Flash point.

Solubility in carbon disulphide (CS_2).

Penetration (consistency) at 39 deg. Fahr. (4 deg. Cent.) and 77 deg. Fahr. (25 deg. Cent.).

Flow point.

Melting-point.

Loss on evaporation at 325 deg. Fahr. (163 deg. Cent.).

Penetration (consistency) of residue at 39 deg. Fahr. (4 deg. Cent.), 77 deg. Fahr. (25 deg. Cent.).

Melting-point of residue.

Free carbon content.

Ash test.

Asphalt. Specific gravity at 60 deg. Fahr. (15.5 deg. Cent.), or 77 deg. Fahr. (25 deg. Cent.).

Flash point.

Solubility in carbon disulphide (CS_2).

Solubility in carbon tetrachloride (CCl_4).

Solubility in petroleum naphtha.

Penetration (consistency) at 39 deg. Fahr. (4 deg. Cent.) and 77 deg. Fahr. (25 deg. Cent.).

Melting-point.

Ductility at 39 deg. Fahr. (4 deg. Cent.) and 77 deg. Fahr. (25 deg. Cent.).

Fixed carbon content and paraffin content.*

Loss on evaporation at 325 deg. Fahr. (163 deg. Cent.).

Penetration (consistency) of residue at 39 deg. Fahr. (4 deg. Cent.), 77 deg. Fahr. (25 deg. Cent.).

Melting-point of residue.

* The fixed carbon and paraffin content tests are of little practical value, but are included here because this fact is not yet generally so accepted.

Ductility of residue at 39 deg. Fahr. (4 deg. Cent.), 77 deg. Fahr. (25 deg. Cent.).

Specific Gravity. Specific gravity is mainly used to differentiate between different tars or bitumens and as a means of identification. The temperature at which the tar or bitumen is tested is a governing factor in the determination of its specific gravity. This temperature, which has been standardized, and always accompanies the specific gravity value, is either 60 or 77 deg. Fahr. (15.5 or 25 deg. Cent.), selected arbitrarily. The specific gravity of the semi-solid asphalts varies with their origin, mode and degree of refinement, and lies between .87 and 1.21 at 77 deg. Fahr. The specific gravity of the tars varies with the method of manufacture and degree of distillation, and lies between 1.10 and 1.25 at 60 deg. Fahr.

The specific gravity* of thin fluid pitches or bitumens is usually determined by the hydrometer method, which consists in selecting the proper hydrometer, inserting it in the material at 77 deg. Fahr. (25 deg. Cent.) and reading the specific gravity off the scale to the third decimal place.

The specific gravity of hard, solid, bitumens is determined by the displacement method, i.e., suspending a small piece of the bitumen by means of a silk thread from the hook of one of the pan supports of an analytical balance, about $1\frac{1}{2}$ inches above the pan and weighed. This is weight "*a*." It is then weighed immersed in water at 25 deg. Cent. and this weight is called "*b*." The specific gravity of the bitumen is then equal to $\frac{a}{a-b}$.

The specific gravity of viscous and semi-solid bitumens is usually determined by the pyknometer method, which requires the following equipment:

A large metal kitchen spoon, a steel spatula or kitchen knife, Bunsen burner and rubber tubing, one 250-c.c. low-form glass beaker, a chemical thermometer reading from 18 deg. Fahr. to 230 deg. Fahr. (−10 deg. Cent. to 110 deg. Cent.), a special pyknometer (Fig. 86), an analytical balance, capacity 100 grams, sensitive to 0.1 mg.

The pyknometer consists of a fairly heavy, straight-walled glass tube, 70 mm. long and 22 mm. in diameter, carefully ground to receive an accurately fitting solid glass stopper with a hole of 1.6 mm. bore in place of the usual capillary opening. The lower part of this stopper is made concave in order to allow all air

* Methods for the examination of bituminous road materials, Bulletin No. 314, U. S. Dept. of Agriculture.

bubbles to escape through the bore. The depth of the cup-shaped depression is 4.8 mm. at the center. The stoppered tube has a capacity of about 24 c.c. and when empty weighs about 28 grams.

When working with semi-solid bitumens which are too soft to be broken and handled in fragments, the following method of determining their specific gravity is employed. The clean, dry pyknometer is first weighed empty and this weight is called "*a*." It is then filled in the usual manner with freshly distilled water at 77 deg. Fahr. (25 deg. Cent.), and the weight is again taken and called "*b*." A small amount of the bitumen should be placed in the spoon and brought to a fluid condition by the gentle application of heat, with care that no loss by evaporation occurs. When sufficiently fluid, enough is poured into the dry pyknometer, which may also be warmed, to fill it about half full, without allowing the material to touch the sides of the tube above the desired level. The tube and contents are then allowed to cool to room temperature, after which the tube is carefully weighed with the stopper. The weight is called "*c*." Distilled water, at 77 deg. Fahr. (25 deg. Cent.), is then poured in until the pyknometer is full. After this the stopper is inserted, and the whole cooled to 77 deg. Fahr., by a 30-minute immersion in a beaker of distilled water maintained at this temperature. All surplus moisture is then removed with a soft cloth, and the pyknometer and contents are weighed. This weight is called "*d*." From the weights obtained the specific gravity of the bitumen may be readily calculated by the following formula:

FIG. 86.—Pyknometer (Hubbard Type), Used to Obtain Specific Gravity of Bitumens.

$$\text{Specific gravity at 77 deg. Fahr./77 deg. Fahr.} = \frac{c-a}{(b-a)-(d-c)}.$$

Flash Point. The flash point of an asphalt determines the possibility of explosions in the melting kettles and general fire risk. It is the temperature at which volatile oils are given off in a gaseous state and which may catch fire. This is guarded against by keeping the flash point as high as possible, that is, refining the asphalts so as to exclude as much volatile oil as practicable. An asphalt with a flash point below 400 deg. Fahr. is not ordinarily used.

Although for ordinary purposes the open-cup method for determining the flash and burning-points of tars and bituminous materials

is reasonably accurate, the closed-cup method described below is to be preferred.

The oil tester consists of a copper oil cup (Fig. 87) having a capacity of about 300 c.c. It is heated in a water or oil bath by a small Bunsen flame. The cup is provided with a glass cover, carrying a thermometer and a hole for inserting the testing flame. The testing flame is obtained from a jet of gas passed through a piece of glass tubing, and is about 5 mm. long.

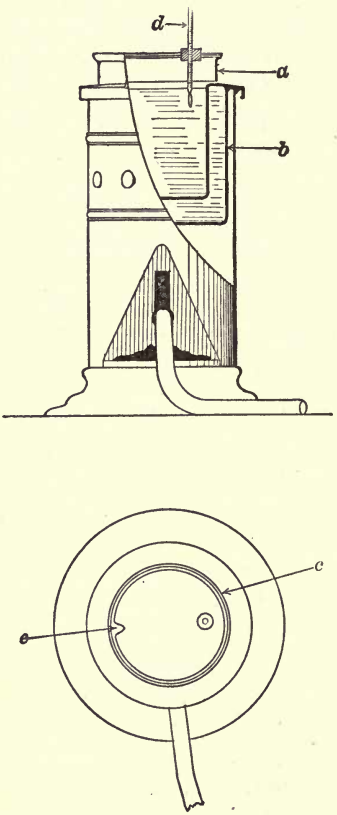


Fig. 87.—New York State Board of Health Oil Tester.

The flash test is made as follows: The oil cup is first removed and the bath filled with water or cottonseed oil, depending on the volatile nature of the material tested. The oil cup is replaced and filled with the material to be tested to within 3 mm. of the flange joining the cup and the vapor chamber above. The glass cover is then placed on the oil cup and the thermometer adjusted so that its bulb is just covered by the bituminous material. The Bunsen flame is then applied in such a manner that the temperature of the material in the cup is raised at the rate of about 9 deg. Fahr. (5 deg. Cent.) per minute. From time to time the testing flame is inserted in the opening in the cover to about half way between the surface of the material and the cover. The appearance of a faint bluish flame over the entire surface of the bituminous material will show that the flash point has been reached and the temperature at this point is taken. The burning-point of the material may be obtained by removing the glass cover and replacing the thermometer in a wire frame. The temperature is raised at the same rate and the material tested as before. The temperature at which the material ignites and burns is taken as the burning-point.

Solubility in Carbon Disulphide. In nearly all asphalts there is a certain quantity of insoluble bitumen present. This insoluble bitu-

men lessens the cementing value of the remainder of the asphalt, raises its melting-point, causes it to become brittle at low temperatures, and otherwise impairs its suitability for waterproofing purposes. A pure asphalt of uniform consistency, containing the highest per cent of soluble bitumen, is the most workable and durable, and the solubility test in carbon disulphide aids the chemist in deciding these points. A determination of the amount of pure bitumen present in any specimen by this test should not show less than 95 per cent.

The test consists in dissolving the bituminous material in carbon disulphide, and recovering any insoluble matter by filtering the solution through an asbestos felt filter. This felt is carefully placed in the bottom of a Gooch crucible, washed several times with water, and drawn firmly against the bottom of the crucible by suction. The crucible used for this determination should be 4.4 cm. wide at the top, tapering to 3.6 cm. at the bottom, and 2.5 cm. deep. The crucible containing the filter is first placed in a drying oven for a few minutes, removed and ignited to red heat over a Bunsen burner, cooled in a desiccator and weighed.

Two grams of bituminous material is then placed in a flask, which has been weighed previously, and the accurate weight of the sample obtained. One hundred cubic centimeters of chemically pure carbon disulphide is poured into the flask, in small portions, with continual agitation, until all lumps disappear and nothing adheres to the bottom. The flask is then corked and set aside for fifteen minutes to allow settlement of the insoluble material.

This solution should then be decanted through the felt filter in the Gooch crucible without stirring up any precipitate that may have settled down. The sides of the flask should now be washed down with a small quantity of carbon disulphide, after which the whole is poured on the felt and suction applied until there is practically no odor of carbon disulphide in the crucible. The crucible and contents should then be dried at 212 deg. Fahr. (100 deg. Cent.) for about twenty minutes, cooled in a desiccator and weighed. The weight of insoluble matter may include both organic and mineral matter. The former must be burned off by ignition at a red heat, thus leaving a mineral matter or ash which is weighed when cool. The difference between the total weight of the material insoluble in carbon disulphide and the weight of substance taken equals the total bitumen. The percentage weights are calculated as total bitumen, and insoluble matter, on the basis of the weight of material taken for analysis. Further detailed information for those partic-

ularly interested in this test will be found in the Transactions of the American Society of Civil Engineers, Vol. 82, p. 1450 (1918).

Solubility in Carbon Tetrachloride. The solubility test in carbon tetrachloride shows whether or not the asphalt has been overheated in refining. The greater the percentage of insoluble bitumen, the greater the overheating; in other words, it indicates the amount of incipient destruction that the asphalt has undergone. This test also determines the amount of other impurities present in the asphalt. The amount of pure bitumen (the soluble part) present in any given specimen should not be less than 95 per cent.

The test is conducted in exactly the same manner as described for "Solubility in Carbon Disulphide," except that 100 c.c. of chemically pure carbon tetrachloride is used in place of carbon disulphide, and the percentage of bitumen insoluble in carbon tetrachloride is reported on the basis of the bitumen taken as 100, the quantity of the bitumen having been determined by the method previously described.

Solubility in Petrolic Ether* (Petroleum Naphtha). The solubility test in petrolic ether is to determine the per cent of petroline present in asphalt, which material is considered to give the viscous or adhesive quality to the asphalt. This test also shows the amount of true bitumen in the asphalt, i.e., the amount of hydrocarbon called "asphaltine." Asphaltine is supposed to possess the greatest durability and resistance to deteriorating agents; it also gives hardness to the asphalt. The petrolic ether dissolves out the petroline, leaving the insoluble asphaltine. A reasonably good asphalt will be greater than 66 per cent soluble in petrolic ether of 88 deg. Baumé.

This determination is made in the same general manner as the test for solubility in carbon disulphide, except that 100 c.c. of 86 to 88 deg. Baumé paraffin naphtha, at least 85 per cent distilling between 95 and 149 deg. Fahr. (35 and 65 deg. Cent.) is employed as a solvent instead of carbon disulphide. Considerable difficulty is sometimes experienced in breaking up some of the heavy semi-solid bitumens; the surface of the material is attacked, but it is necessary to remove some of the insoluble matter in order to expose fresh material to the action of the solvent. It is, therefore, advisable to heat the sample after it is weighed, allowing it to cool in a thin layer around the lower part of the flask. If difficulty is still experienced in dissolving the material, a rounded glass rod will be found convenient for breaking up the undissiolved particles. Not more than one-half of the total amount of naphtha required

* U. S. Dept. of Agriculture. Bulletin No. 314, Dec. 10, 1915, p. 28.

should be used until the sample is entirely broken up. The balance of the 100 c.c. is then added, and the flask is twirled a moment in order to mix the contents thoroughly, after which it is corked and set aside for thirty minutes.

In making the filtration the utmost care should be exercised to avoid stirring up any of the precipitate, in order that the filter may not be clogged and that the first decantation may be as complete as possible. The sides of the flask should then be quickly washed down with naphtha and, when the crucible has drained, the bulk of insoluble matter is brought upon the felt. Suction may be applied when the filtration by gravity almost ceases, but should be used sparingly, as it tends to clog the filter by packing the precipitate too tightly. The material on the felt should never be allowed to run entirely dry until the washing is completed, as shown by the colorless filtrate. When considerable insoluble matter adheres to the flask no attempt should be made to remove it completely. In such cases the adhering material is merely washed until free from soluble matter, and the flask is dried with the crucible at 100° deg. Cent. for about one hour, after which it is cooled and weighed. The percentage of bitumen insoluble is reported upon the basis of total bitumen taken as 100.

The difference between the material insoluble in carbon disulphide and in the naphtha is the bitumen insoluble in the latter. Thus, if in a certain instance it is found that the material insoluble in carbon disulphide amounts to 1 per cent and that 10.9 per cent is insoluble in naphtha, the percentage of bitumen insoluble would be calculated as follows:

$$\frac{\text{Bitumen insoluble in naphtha}}{\text{Total bitumen}} = \frac{10.9-1}{100-1} = \frac{9.9}{99} = 10 \text{ per cent.}$$

Penetration Test.* Consistency of an asphalt is a measure, especially in commerce, of its hardness and softness at various temperatures, and this property is usually determined by the penetration test. The greater the penetration, the softer is the bitumen. All coal-tar pitches and asphalts have the property of being softened by heat and hardened by cold, hence it is necessary to determine to what degree they are so affected. It is evident that the less a pitch or asphalt is changed in consistency by changes in temperature, the more desirable it is as a waterproofing material. But what the penetration of coal-tar pitch or asphalt for waterproofing should be depends largely on the specific use they will be put to.

* Journal of Industrial Engineering Chemistry, Vol. 6, No. 2, February, 1914.

The test is performed on a standard machine called a penetrometer. Penetrometers consist essentially of a needle of specified size (Roberts No. 2) fixed in a rod, the rod and needle being of, or loaded to, definite weights. A clamp on the body of the instrument holds the rod with the needle, which, on being released, allows the latter to penetrate as nearly as possible without friction. A device for measuring the amount the needle has penetrated after it has been released for a specified time and again grasped by the clamp is also included. (The Dow penetrometer is constructed on this basis.) The penetration is expressed in hundredths of a centimeter, though it is not always designated so. Penetrations are most commonly made at 77 deg. Fahr. (25 deg. Cent.), with the needle loaded to 100 grams penetrating for five seconds. In order to ascertain the extent a bitumen will harden when chilled to 32 deg. Fahr. (0 deg. Cent.), penetrations are frequently made at this temperature with the needle loaded to 200 grams penetrating for one minute. A new form of penetrometer electrically controlled and timed is shown in Fig. 88. A new and much more accurate machine of this type, called a consistometer, in which the needle is replaced by a rod and penetration or consistency is measured by volume displacement, is described in the Proceedings of the American Society for Testing Materials, Vol. 11, 1911. For a more detailed description of the Penetration Test see Transactions of the American Society of Civil Engineers, Vol. 82, p. 1454 (1918).

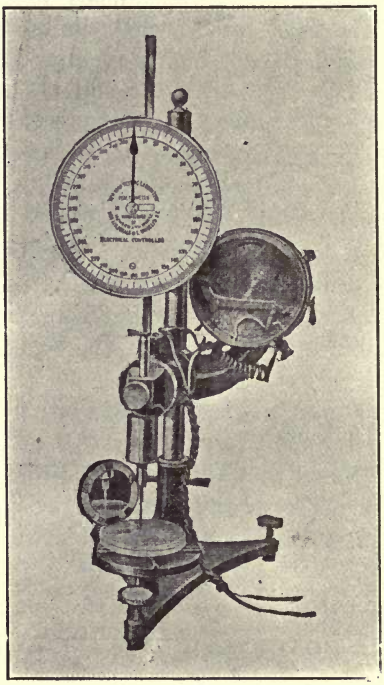


FIG. 88.—Electrically Controlled Penetrometer.

Methods of Determining Melting-points of Bitumens

There are nine or more different methods of obtaining the melting-point of bitumen, giving results varying by as much as 30 and 40 deg. Fahr. What causes the real trouble, though, is that chemists are at variance as to which method is most nearly correct. The technique of the methods differs so considerably that it is difficult or impossible to note any definite relation between the results obtained with each method.

But, as a matter of fact, all methods are more or less incorrect. They all depend on varying, arbitrary factors and special technique. They all attempt to determine the melting-point of materials that have no melting-point. Pitch and asphalt have no melting-point for the reason that they are composed of complex mixtures of hydrocarbons, which are of indefinite consistence and specific gravity.

Were it possible to measure in absolute units the fluidity of a pitch or asphalt, this would furnish the ideal method, but as this seems unattainable it would be advisable to select one method possessing the most practicable apparatus and technique. Or perhaps a new method could be evolved embodying the good features of all the present ones. Up to the present time nothing has been done to co-ordinate these methods.

However, one thing is certain, any method, the results of which are influenced by the specific gravity of the material tested is wrong. This refers particularly to what is known as the "Cube-in-water Method," described below. For instance, the average specific gravity of asphalt derived from paraffin petroleum is 0.961; from asphaltic petroleum, 1.004. The buoyant effect of the material whose specific gravity is so nearly unity is obvious, hence no worthwhile melting-point is found by the cube-in-water method. This is equally the case when applied to coal-tar pitch, whose specific gravity varies with the method of manufacture or reduction as follows: * Gas-house tars, 1.22; coke-oven tars, 1.18; water-gas tars, 1.10. A standard method of finding the melting-point of bitumens ought to be established for general use for all laboratories; or else it should become the general practice to state the method whenever the melting-point of a bitumen is given, otherwise, as at present, this value is practically meaningless.

Nearly all the other properties of pitch or asphalt are modified by the melting-point. It is, in fact, a measure of the fluidity, con-

* "Some experiments on Technical Bitumens," by S. R. Church, American Society for Testing Materials, April, 1915.

sistency and ductility of these materials. But because it is an arbitrary value, dependent to a great extent on the method of test, it is not as reliable as its importance warrants. The nine methods explained below, are more or less used in industrial plants and laboratories, but no one method predominates. These are:

1. Ring-and-ball Method.
2. Cube-in-air Method.
3. Cube-in-water Method.
4. Kraemer-and-Sarnow Method.
5. New York Testing Laboratory Method.
6. Mabery-Sieplein Method.
7. Richardson Method.
8. General Electric Method.
9. Drop Point Test.

Ring-and-ball Method. The apparatus of the C. I. Robertson or the ring-and-ball method consists of a brass ring $\frac{5}{8}$ inch in diameter, $\frac{1}{4}$-inch deep, $\frac{3}{32}$-inch wide; a steel ball $\frac{3}{8}$ inch in diameter, weighing 350 grams; a standard thermometer; a glass beaker, about 600-c.c. capacity. The test is made as follows:

Press the ring full of the bitumen, cutting it off slightly with a hot knife. Place the ball in the center of the ring and suspend the apparatus in a beaker of water, the ring and ball being about 1 inch from the bottom of the beaker; also suspend a thermometer in the beaker of water to the same depth. Heat up at the rate of 9 deg. Fahr. (5 deg. Cent.) per minute. The melting-point is that temperature at which the ball drops through the ring (and reaches the bottom of the beaker). The bitumen in the ring usually sags down before the melting-point is reached, but the temperature of the water at the time the ball reaches the bottom of the beaker is the temperature recorded as the melting-point.

For testing bitumen having a melting-point above 110 deg. Fahr. (43 deg. Cent.) the sample should first be cooled to 50 or 77 deg. Fahr. (10 or 25 deg. Cent.). For testing bitumen having a melting-point above 210 deg. Fahr. (99 deg. Cent.) the sample should be cooled to 60 or 100 deg. Fahr. (15.5 or 38 deg. Cent.).

Cube-in-air Method. The material under examination should be melted in a spoon by the gentle application of heat until sufficiently fluid to pour readily. Care shall be taken that it suffers no appreciable loss by volatization. It shall then be poured into a 12.7-mm. (0.5-inch) brass cubical mold, which shall have been amalgamated with mercury and shall be placed on an amalgamated

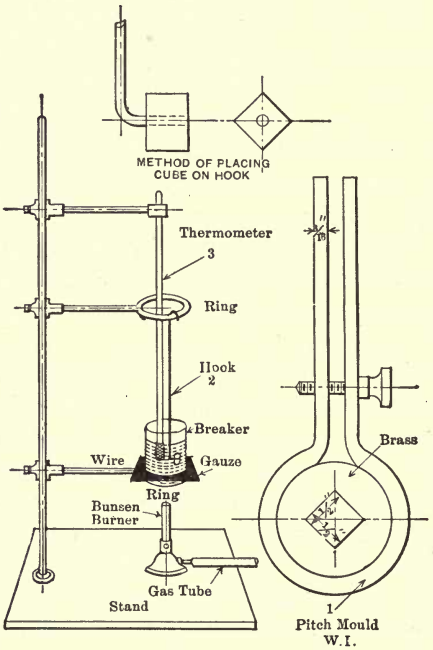
brass plate. The hot material shall slightly more than fill the mold, and, when cooled, the excess shall be cut off with a hot spatula.

After cooling to room temperature, the cube shall be removed from the mold and fastened on the lower arm of a No. 10 wire (B. and S. gauge), bent at right angles at one end and suspended beside a thermometer in a covered Jena glass beaker having a capacity of 400 c.c. (13.526 ounces), which shall be placed in a water bath, or, for high temperatures, a cottonseed-oil bath. The wire shall be passed through the center of two opposite faces of the cube, which shall then be suspended with its base 25.4 mm. (1 inch) above the bottom of the beaker. The water or oil bath shall consist of an 800-c.c. (27.051 ounces) low-form Jena glass beaker suitably mounted for the application of heat from below. The beaker in which the cube is suspended shall be of the tall-form Jena type, without lip. The metal cover shall have two openings. A cork, through which passes the long arm of the wire, shall be inserted in one hole and the thermometer in the other. The bulb of the thermometer shall be just level with the cube and at an equal distance from the side of the beaker.

After the test specimen shall have been placed in the apparatus, the liquid in the outer vessel shall be heated in such a manner that the thermometer registers an increase of 9 deg. Fahr. (5 deg. Cent.) per minute. The temperature at which the bituminous material touches the bottom of the beaker shall be taken as the melting-point. Determinations made in the manner described shall not vary more than 3.6 deg. Fahr. (2 deg. Cent.) for successive trials on the same material. At the beginning of this test the temperature of both bituminous material and bath shall be approximately at 77 deg. Fahr. (25 deg. Cent.).

Cube-in-water Method. The cube-in-water method consists of (1) the use of apparatus shown in Fig. 89; (2) the manipulation of same, as follows. (For bitumens with a melting-point of 110 deg. to 170 deg. Fahr. (43 to 77 deg. Cent.)). A clean, well-shaped $\frac{1}{2}$-inch cube of the bitumen is formed in the mold, as described under the cube-in-air method above, placed on the hook of the No. 12 wire and suspended in a 600-c.c. beaker, so that the bottom of the bitumen is 1 inch above the bottom of the beaker. The bitumen should remain five minutes in 400 c.c. of water at a temperature of 60 deg. Fahr. (15.5 deg. Cent.) before heat is applied. Apply heat in such a manner that the temperature of the water is raised 9 deg. Fahr. (5 deg. Cent.) per minute. The temperature recorded by the thermometer (which is at the same depth as the bitumen when the test

is started), at the instant the bitumen touches the bottom of beaker is considered the melting-point. For bitumens with a melting-point below 110 deg. Fahr. (43 deg. Cent.) the same method can be used except that at the start the water should have a temperature of 40 deg. Fahr. (4 deg. Cent.). For bitumens 170 deg. Fahr. (77 deg. Cent.) up, cottonseed oil should be substituted for water, otherwise the method remains the same.



MELTING-POINT TEST
No. 1. Pitch Mould (Special).
No. 2. Hook; Made of #12 Copper Wire.
No. 3. Thermometer.

FIG. 89.—Apparatus for Determining the Melting-point of Bitumen by the Cube-in-water Method.

Kraemer-and-Sarnow Method.* The Kraemer-and-Sarnow method of making the melting point test for asphalts, tars, etc., is as follows: Some asphalt in a layer 10 mm. thick is melted in a beaker contained in an oil bath. Into this is dipped an open-end glass tube 10 cm. long and 6 or 7 mm. internal diameter. The upper end of the tube is closed with the finger, the tube is removed and the asphalt is allowed to solidify in the tube while it is held horizon-

* Peckhan's "Solid Bitumens," p. 272.

tally and rotated. When the asphalt has set the portion adhering to the outside is removed. The length of the column inside the tube will be about 5 mm. On top of this is poured 5 grams of mercury. The tube containing the asphalt and mercury is then suspended in a beaker full of oil or water resting in another beaker also full of oil or water. The inner beaker contains a thermometer, the bulb of which stands at the same level as the asphalt. The outer beaker is heated by means of a small flame. The temperature of the

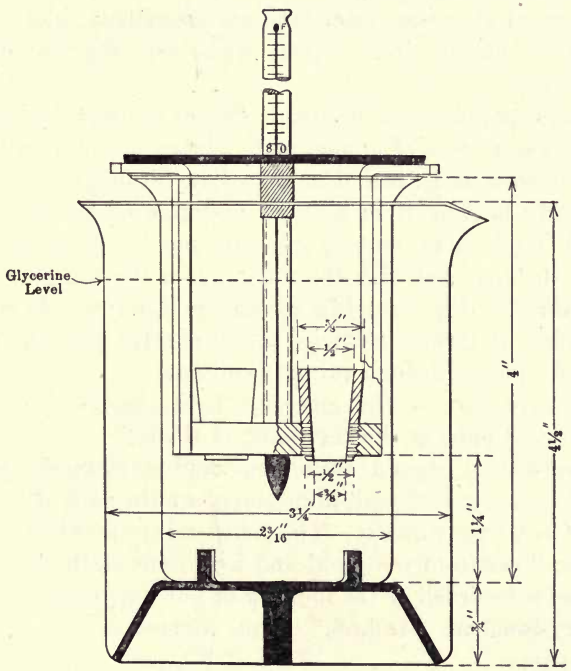


FIG. 90.—Apparatus for the Determination of the Melting-point of Bitumen by the New York Testing Laboratory Method.

asphalt and thermometer being thus raised uniformly at the rate of 9 deg. Fahr. (5 deg. Cent.) per minute.

The temperature recorded when the mercury falls through the layer of asphalt is taken as the melting-point. This method depends for its accuracy upon the diameter of the tube, the thickness of the asphalt and the height of the mercury in the tube above the asphalt.

New York Testing Laboratory Method. The air method for determining the melting-point of semi-solid or solid bitumens requires the apparatus shown in Fig. 90 and described below.

Outer vessel or container for the glycerine bath, 600 c.c. Griffin type Jena beaker.

Inner vessel of air bath, 200 c.c. tall lipless Jena beaker.

Chair or support for inner vessel, cut out of $\frac{1}{16}$-inch sheet aluminum.

Cover for inner vessel, cut out of sheet aluminum or brass.

Support for molds, disc of brass with tapped holes for two or four molds suspended on three hangers.

Molds for shaping bitumen.

Commercial glycerine; standard thermometer; double thickness 20-mesh iron gauze; iron tripod, stand and clamps; Bunsen or alcohol burner.

The test is performed as follows: One or more of the brass molds, standing upon a piece of amalgamated brass or tin, should be filled with the bitumen under examination. The bitumen may be softened by cautiously heating it in a small casserole or tin box until it is sufficiently fluid to be poured into the mold. After trimming off the upper surface level with the mold, place the sample in water at 77 deg. Fahr. (25 deg. Cent.) for about ten minutes. It should then be suspended in the air bath of the apparatus and the cover and thermometer placed in their proper positions.

The temperature of the glycerine bath should also be 77 deg. Fahr. (25 deg. Cent.) at the beginning of the test.

The apparatus should stand on double 20-mesh iron gauze, supported on an iron tripod, and heated at the rate of 5 deg. Fahr. (2.6 deg. Cent.) per minute. The temperature at which the sample of bitumen flows from the mold and first touches the bottom of the inner vessel is recorded as the melting or flowing point.

Mabery-Sieplein Method.* The apparatus consists of the following parts:

One Jena beaker, 600 c.c. and one 400 c.c. capacity, tall forms without lips.

One wooden stopper to fit 400-c.c. beaker; stopper to have two holes, one of $\frac{1}{8}$ inch diameter, in exact center, one of sufficient size to admit thermometer $\frac{3}{8}$ inch from center.

One metal shelf, $\frac{1}{2}$ by $1\frac{1}{4}$ by $\frac{1}{64}$ inch thick, in the center of which and at right angles to which is fastened a rod of $\frac{1}{8}$ inch diameter.

Mold which will prepare a tablet of asphalt 1 by $\frac{1}{2}$ by $\frac{1}{8}$ inch.

One standard gas-filled thermometer reading to 300 deg. Fahr. (149 deg. Cent.).

Liquid medium to serve as bath (such as anhydrous glycerine to

* Journal American Chemical Society, Vol. 23, p. 16.

be used for temperature up to 280 deg. Fahr. (138 deg. Cent.), linseed oil above 280 deg. Fahr.) A slightly modified apparatus is shown in Fig. 91.

The 400-c.c. beaker is set inside the 600-c.c. beaker, and the space between is filled with the proper liquid to expand to approximately within $\frac{1}{2}$ inch of the top of the beaker when heated to 280

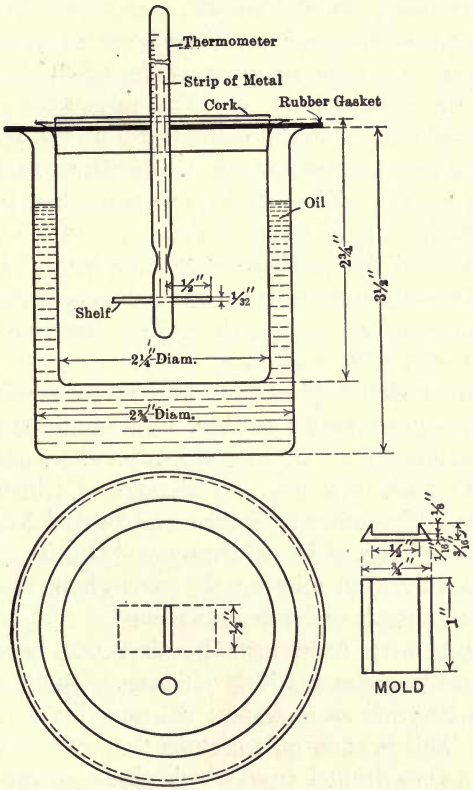


FIG. 91.—Apparatus for Determining the Melting-point of Bitumen by the "Mabery-Sieplein" Method.

deg. Fahr. The $\frac{1}{8}$-inch rod supporting the shelf is inserted through the central hole in the stopper and set so that the top of the shelf is exactly 1 inch from the bottom of the beaker. The thermometer is inserted in the other opening and is set so that the top of the bulb is $\frac{1}{8}$ inch above the top of the shelf and the bulb itself is $\frac{3}{8}$ inch from the rod supporting the shelf.

At least 1 ounce of the sample to be examined is carefully melted at as low a temperature as possible, care being taken, however, to see

that it is sufficiently liquid to completely fill the mold and allow the escape of any confined air. The asphalt* is then poured into the mold, which has previously been amalgamated by brushing with a solution of nitrate of mercury. When the asphalt has cooled the specimen is removed from the mold and placed on the shelf in such a position that the longest side of the specimen is at right angles to the longest side of the shelf, and lies perfectly flat so that an equal amount of the specimen extends on either side beyond the edge of the shelf. Care should of course be taken that the specimen just touches the supporting rod. The apparatus is then heated gradually by suitable means, preferably by an electric oven, allowing at least fifteen minutes for the temperature to reach 120 deg. Fahr. (49 deg. Cent.). When this point is reached the temperature is increased at the rate of 6 deg. Fahr. (3.3 deg. Cent.) per minute until the portions of the specimen extending beyond the sides of the shelf have sufficiently softened so that they have dropped to the bottom. The temperature at which the asphalt just touches the bottom of the beaker is the melting-point.

Richardson or Pellet Method. The melting-point of bitumen by the Richardson or Pellet method is determined as follows: A thin porcelain dish, about $2\frac{1}{4}$ inches in diameter, and with $1\frac{1}{2}$-inch sides, filled with clean mercury to a distance of $\frac{1}{4}$ inch from the top, is placed over a 20-mesh wire gauze and heated by a small flame protected from draughts by a chimney. On the surface of the mercury is placed a thin microscopic cover-glass, No. 2-0, carrying the specimen of asphalt under examination.

When dealing with hard asphalts that can be ground rather coarsely, several fragments, which will pass a 40-mesh sieve and be retained on a 50-mesh sieve (about .50 mm. diameter), are spread on the glass. This is then placed upon the surface of the mercury, covered with a glass funnel, from which the stem has been cut and the thermometer passed through the orifice until the bulb is immersed in the mercury. It is held in position by a clamp attached to a ring-stand on which rests the dish. Under the dish a Bunsen burner is placed and regulated to a small flame, or so that the dish is heated at the rate of 5.4 to 9 deg. Fahr. (3 to 5 deg. Cent.) per minute. In a short time it would be noticed that the specimens will have changed from the brown or brownish-black color of the powder to that more nearly approaching the original, with a slight rounding of the individual grains. On further heating, these globules flow

* This method is to be used only on asphalt having a penetration less than 105 at 77 deg. Fahr. (25 deg. Cent.).

together and form a thin sheet on the glass. The temperature as indicated by the thermometer, at which the specimen begins to flow, is taken as the melting-point.

Asphalts that cannot be ground are softened and pulled out to a thread and cut into small pieces, about 1 c.mm. Several pieces should be placed on the glass together, as one will serve as a check on the other, and thereby lessen the chance of error. The softening-point may be noted by the rounding of the particles and the melting-point by the beginning of the flow, or when the specimen begins to spread out (which is always at the point of contact with the glass), is set down as the temperature at which the specimens will melt.

General Electric Method. This method is quite simple and consists of heating a quantity of the bitumen to be tested in a small can until liquid. The can containing the liquified bitumen is placed on a gram scale and balanced up. Then the scale is set 2 grams back and enough bitumen is taken out to rebalance the scale. The bitumen is to be removed by immersing the bulb of an ordinary Fahrenheit thermometer about $1\frac{1}{4}$ inches, or to about the 20-degree point. As the thermometer is dipped into the liquid it should be turned so as to get an even coating all over the surface covered. Then the thermometer should be held horizontally and turned constantly until the coating of bitumen is cooled. Next the thermometer is placed in a large test tube, which in turn is immersed in a beaker filled with glycerine. The beaker is then heated over a Bunsen burner at the rate of 7.2 deg. Fahr. (4 deg. Cent.) per minute. The test tube should have a small amount of glycerine placed in it. The thermometer is run through a cork large enough to support it $\frac{1}{2}$ inch above the glycerine. The temperature, as read directly on the thermometer, at which the bitumen drops and touches the glycerine is regarded as the melting-point. Fig. 92 shows the arrangement of the apparatus.

Drop Point and Softening-point of Bituminous Compounds. The inventor of an apparatus for determining the drop-point test, Mr. H. W. Fisher,* says that his investigation showed: first, that a large majority of bituminous compounds, unlike minerals, have no well-defined melting-point; that what some chemists specify as a melting-point is really a softening-point of the material; and third, that the melting-point as used by chemists corresponds to the temperature at which the compound will drop; hence, he believes that instead of using the misnomer "melting-point," it would be more practical to speak of the softening-point and drop point of compounds.

* Proceedings of American Society for Testing Materials, Vol. 11, 1911.

Fig. 93 gives a working drawing of an apparatus designed to put this idea into practice. For making the drop-point test, the compound in placed in hole 2, Fig. 93, *A*, hole 1 being the vent hole. Hole 2 can conveniently be filled by inverting the apparatus and letting the compound drip from a heated wire against which it is held. During this operation the vent hole should, of course, be filled with the rod *f*. The apparatus and rod are then cooled, after which the rod is removed. The surplus compound is removed so that its surface is flush with the bottom surface of the hole.

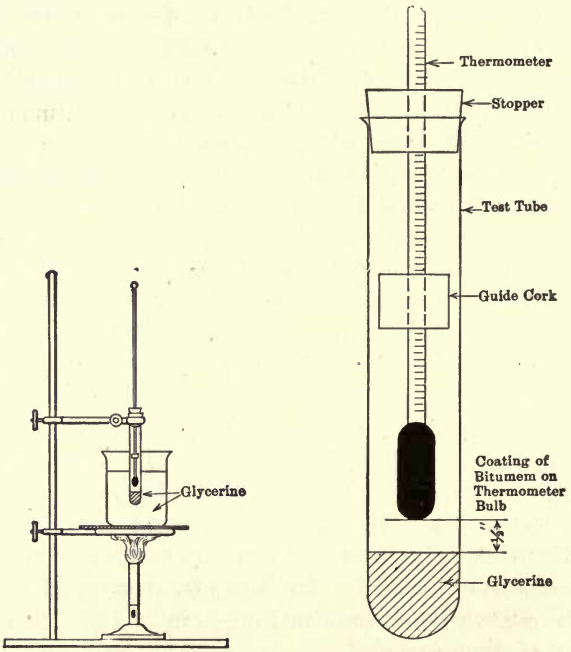


Fig. 92.—Apparatus for Finding the Melting-point of Bitumen by the "General Electric" Method.

For making the softening-point test, the nipple shown in Fig. 93, (*d*) is provided. A wrench for removing and inserting the nipple is shown at (*e*). The rod (*f*) is placed into the nipple through vent hole 4, after which both are heated above the melting-point of the compound. The compound hole 3 is then filled, and after partial solidification the rod is removed and the surplus compound cut off flush with the top of the nipple. Afterwards, the nipple is screwed into place as shown at Fig. 93 (*c*).

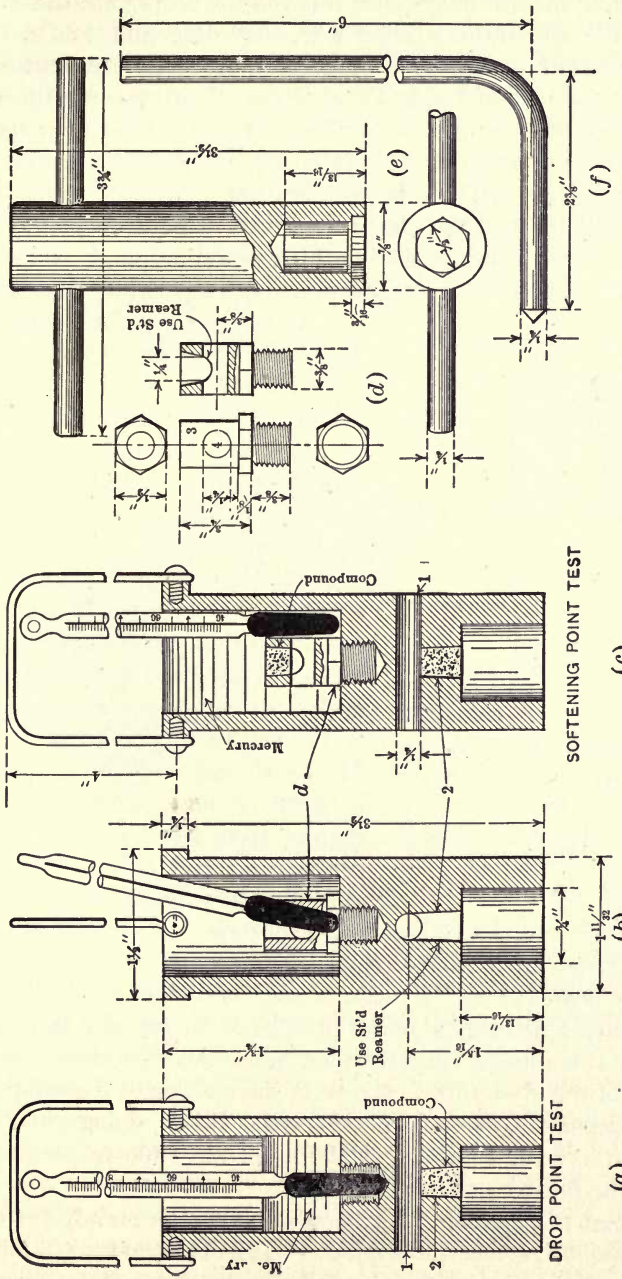


FIG. 93.—Apparatus for Determining the Drop Point and the Softening-point of Bituminous Compounds.

For making the softening-point test and the drop-point test in one operation, the apparatus is filled with the compound, and a thermometer inserted as shown in Fig. 93 (*c*). The temperature is increased at the rate of 7 deg. Fahr. (4 deg. Cent.) per minute until the compound comes up through the mercury. The temperature at which this occurs is called the softening-point of the the compound. Continuing the test further, the temperature at which a drop of the compound falls through the glass tube is called the drop point of the compound. If the compound has a high softening-point and a high melting-point, a somewhat greater rise of temperature per minute is admissible to within about 30 deg. Fahr. (16.6 deg. Cent.) of the softening-point.

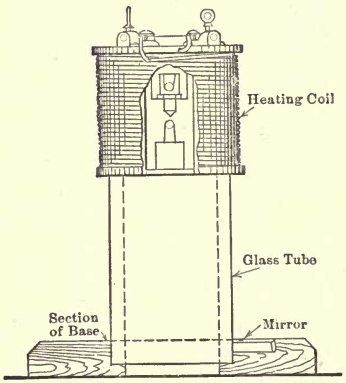


FIG. 94.—Electric Apparatus for Applying Heat Uniformly to the Apparatus for Determining the Drop Point and Softening-point of Bituminous Compounds.

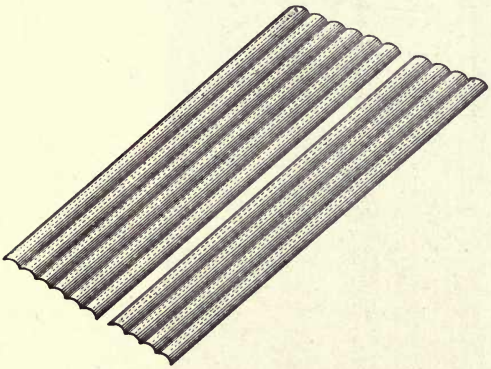
Fig. 94 illustrates the method by which heat is applied uniformly over the entire apparatus. A fiber spool approximately $1\frac{9}{16}$ inches inside diameter, 3 inches long, and 4 inches outside diameter, is wound with about 240 turns of No. 12 D.C.C. magnet wire. By means of alternating current of 60 cycles, the iron testing apparatus is heated to any desired degree. The voltage employed varies between 30 and 55 volts, and the current from 4 to 8 amperes. For use with a direct current on a 110-volt circuit, wire of half the size should be used, and the voltage could be varied between 60 and 110 volts. By either method the temperature can be kept almost constant at any degree or can be made to vary as desired.

The testing apparatus and coil are placed on top of a large glass tube which is embedded in a wooden base. By means of a mirror at the side of the glass tube in the base, the melting of the compound in the drop-point test can be observed. When doing this, it is necessary to have an incandescent lamp on the opposite side of the base from the mirror.

Flow Point of Bitumen. The flow-point test is mainly for comparison of roofing pitches and asphalts. It is a method for obtaining the relative flow, or progressive tendency to glide, of one asphalt or pitch with another accepted as a standard, under the following

condition: On a corrugated strip of metal called a flow plate (Fig. 95, *A*), 8 inches long and 2 inches to 4 inches wide, two pills of equal volume (made in a flow mold, Fig. 95, *B*), one of each material, are placed side by side but in separate grooves on one end of the plate. The plate is then placed in an air bath with the loaded end $2\frac{1}{2}$ inches higher than the other. The whole is then placed in a water bath and heated to the boiling-point. This temperature is maintained for an arbitrary period of time and then the glide of each material is measured. If the tested material is longer than the standard material, this indicates that it is softer; if the reverse obtains, that it is harder.

As a practical test the flow point is quite serviceable in comparing the relative flow of roofing pitches and asphalts, but it is not serviceable and in fact is not used on waterproofing bitumens. It



A - FLOW PLATES

B - FLOW MOLD

FIG. 95.—Mold and Plate for Flow-point Test.

bears no direct relation to either the melting-point or the penetration of the pitch or asphalt tested.

Ductility Test on Bitumen. It is generally true that the greater the ductility of an asphalt, i.e., the extent to which it is capable of being drawn out in the form of a fine thread, the greater its cementing or cohesive value. The main function of the ductility test, however, is to reveal the possible amount of healing to be expected in a fractured bitumen in the form of applied waterproofing. For a given penetration, the greater the ductility of an asphalt, the greater the healing or cohesive quality. Except when used for joint fillers and other special purposes, no asphalt should have a ductility less than 20 cm. at 77 deg. Fahr. (25 deg. Cent.).

The test as made on the Abraham Tensometer* is shown in

* Proceedings of American Society for Testing Materials, Vol. 10, 1910.

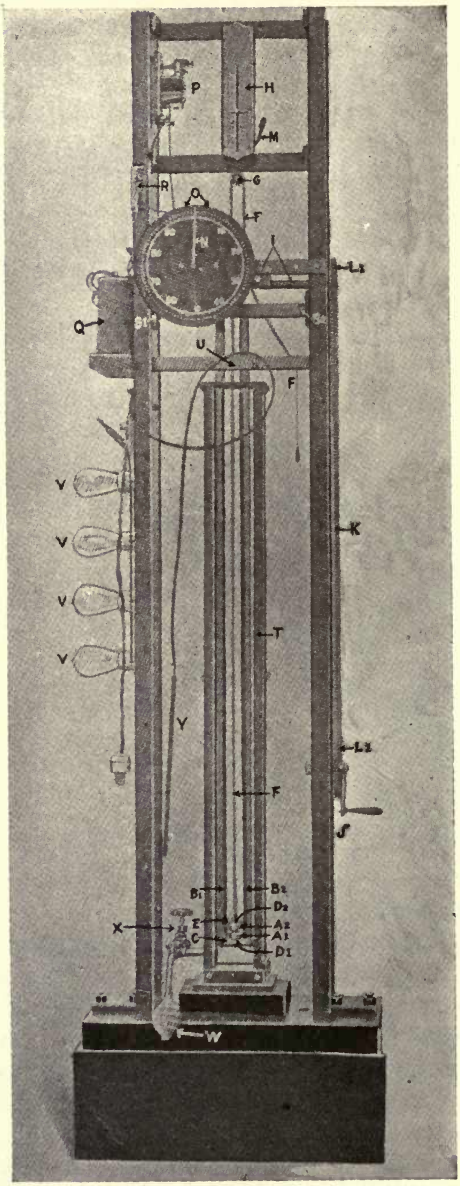


FIG. 96.—Abraham's Tensometer.

Fig. 96. In this instrument the mold is the most vital part. In its new and improved form it consists of two cylindrical hardened steel sections (Fig. 97), resting together on circular knife edges and maintained in that position by three guide rods. The cross-section at the knife edges is exactly 1 sq. cm. The further ends of these two cup-like sections are threaded, and bear the outer caps which serve to fasten the mold in the instrument.

After warming the mold, it is filled by unscrewing the upper cap, bringing the two sections firmly together and pouring in the melted bituminous substance, which assumes the form of a rivet, the smallest cross-section of which has an area of exactly 1 sq. cm. Then it is

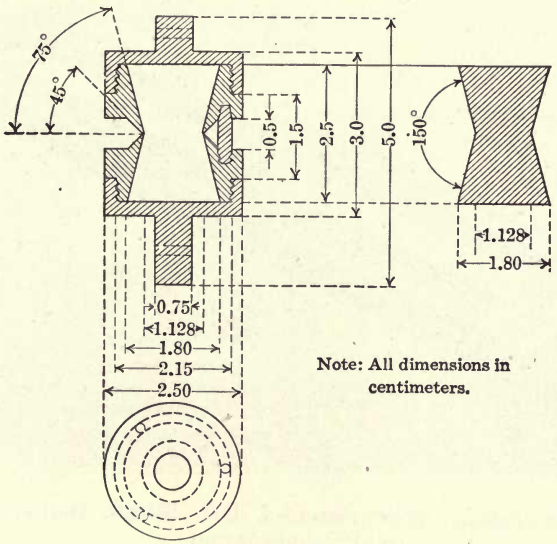


Fig. 97.—Details of Mold for Abraham's Tensometer.

replaced in the machine and drawn apart until it breaks; the distance thus traversed being recorded as the ductility of the specimen. Detailed information on this instrument may be found in the Proceedings of the American Society for Testing Materials, Vols. 10 and 11, 1910 and 1911.

A simpler and more commonly used machine, the "Smith Ductility Machine," is shown in Fig. 98. The preliminary treatment of the bitumen and the preparation of the briquette for testing it with this machine are conducted as follows: The mold is placed upon a brass plate. To prevent the asphalt from adhering to the plate and the inner side of the two removable pieces of the mold, they

are well amalgamated. The different pieces of the mold are held together in a clamp or by means of an India rubber band.

The material to be tested is poured into the mold while in a molten state, a slight excess being added to allow for shrinkage on cooling. After the bitumen is nearly cooled, the briquette is smoothed off level by means of a heated palette knife. When cooled, the clamp is taken off and the two center pieces of the mold removed, leaving the briquette of asphalt firmly attached to the two ends of the mold, which serves as clips. The briquette is then immersed in water maintained at 77 deg. Fahr. (25 deg. Cent.),

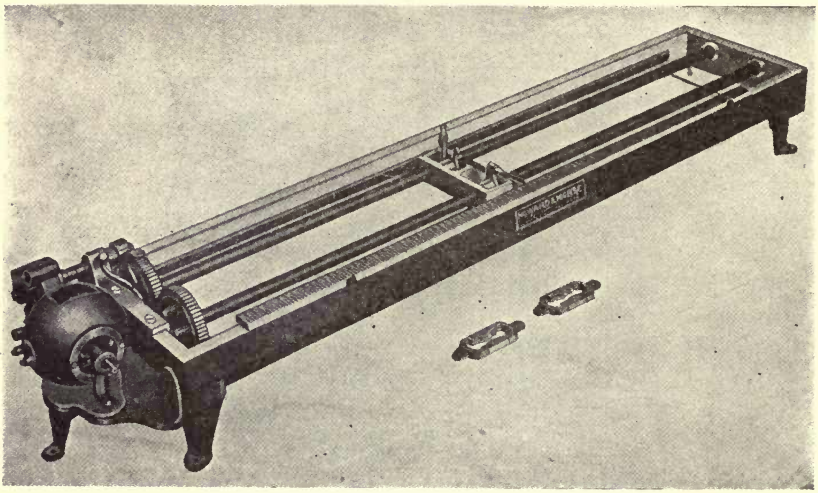


FIG. 98.—The "Smith," Direct-connected, D.C. Electric Ductility Machine and Briquette Forms.

for at least thirty minutes, or until the whole mass of bitumen is at that temperature. It is then placed in the machine and pulled apart as follows: The pointer is set at zero on the centimeter rule, and a thermometer is placed through a cork in the carriage, which will test the variation in the temperature of the water which may take place during the test. The distance registered by the pointer at the moment the thread of bitumen breaks gives the ductility, expressed in centimeters, of the sample under examination.

Evaporation Test on Bitumen. In practice it is often necessary during waterproofing operations to keep pitch or asphalt for a long time in a molten condition at between 250 and 350 deg. Fahr. (121 and 177 deg. Cent.). The pitch or asphalt which will volatilize

off the least amount of oil and be the least changed in consistency by this heating is the most desirable. A heating test is therefore performed to determine the amount of loss of volatile oil during an arbitrary period of time. This, combined with the penetration of the residue left after such heating, is taken as a measure of the hardening effect to be expected, due to aging of the tar and bitumen materials. The reason for this is that evaporation and hardening go on continuously, though slowly, after the waterproofing is in place. To guard against rapid hardening and consequent brittleness of the bitumen, it is desirable to use an asphalt which will not lose more than 1 per cent and a pitch which will not lose more than 6

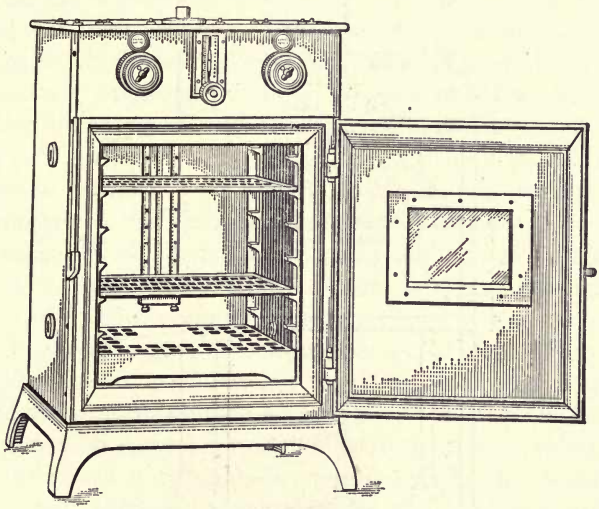


FIG. 99.—"Frea's" Electric Oven. (Chamber, 12 by 12 by 12 Inches.)

per cent in weight when heated for five hours at 325 deg. Fahr. (163 deg. Cent.) in an electric oven, and not more than 3 per cent and 9 per cent respectively in a gas oven. After such heating, neither bitumen shall have its penetration reduced more than one-half the original. The different amounts volatilized in each oven is due to the relative restricted circulation of air in the electric oven.

This test* is usually made on 50 grams of bitumen which are weighed in a flat-bottomed dish, $2\frac{3}{16}$ inches inside diameter, and $1\frac{3}{8}$ inch deep, placed in the oven and held exactly at 325 deg. Fahr. (163 deg. Cent.) for five hours. Then it is cooled in a desiccator, and the loss in weight is noted. The electric oven shown in Fig. 99 is some-

* Journal of Industrial and Engineering Chemistry, Vol. 3, No. 4, April, 1911.

times used but gives lower results than the gas oven. Therefore specifications should state the type of oven to be used for the test.

The gas oven shown in Fig. 100, which is still widely used, has the top and sides covered with 1.8-inch asbestos. The shelf is provided with a $\frac{1}{4}$-inch asbestos pad, large enough to accommodate the dishes. The bulb of a Centigrade thermometer should be 1 inch above the shelf and the emergent stem should show the 90-degree mark. Not more than four tests must be run in the oven at a time.

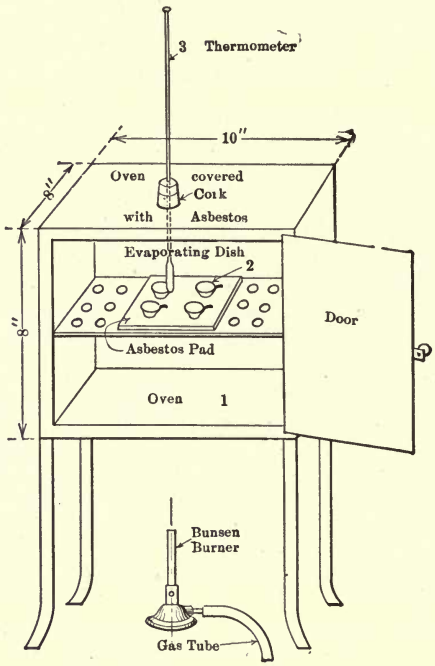


FIG. 100.—Drying and Evaporating Gas Oven.

1. Chamber, 8 by 8 by 12 inches, asbestos covered. 2. Dishes, 2 inches diameter, centrally located. 3. Thermometer.

Determination of Free Carbon in Coal-tar Pitch. It has been stated that free carbon in pitch is an impurity from a chemical standpoint. This is not correct, as the so-called free carbon content in pitch is normally produced in the tar itself during the destructive distillation of bituminous coal in gas retorts or by-product coke ovens. This free carbon is present not as an impurity but as a product of the decomposition of hydrocarbon vapors during their travel along the heated walls of the retort or oven. It is a black, organic, powder held in suspension by the tar and probably consists, not only

of free carbon, but also of hydrocarbons extremely rich in carbon. Actual analysis* show this free carbon to be composed of approximately as follows:

Carbon	89.85
Hydrogen	3.30
Nitrogen	1.10
Oxygen	3.13 (by difference)
Sulphur	1.28
Mineral ash	1.34

The presence of more or less free carbon in tars is due to the heats at which the tar is produced and the size and shape of the retort, and the consequent relation between the quantity of vapors and surface of hot walls at which the vapors are exposed. Hence the production of free carbon is attended by the production of other characteristic hydrocarbon compounds, and the free carbon content of pitch is therefore, to a great extent, an index of the character of the hydrocarbon in the bitumen. In general, low temperature tars contain smaller amounts of free carbon and are characterized by the presence of large amounts of phenol bodies and sometimes paraffin compounds. The tars produced at higher temperatures containing more free carbon also contain large quantities of the characteristic aromatic hydrocarbons. Therefore, the belief that pitch can be made artificially to meet certain specifications, after introducing into an otherwise pure bitumen an adulterant of lamp black, or other carbon, cannot be substantiated, for such a mixture would violate the requirement of a straight-run pitch, and in the second place, while the result produced might contain the necessary amount of free carbon, it would not produce the characteristic bitumen accompanying the normal free carbon content.

Experience of years has even demonstrated that for certain purposes, and particularly for roofing and waterproofing work, pitch, fairly high in free carbon (containing between 20 and 30 per cent) is much more staple and less susceptible to temperature changes than pitches of low free carbon.

The test to determine the free carbon content of bitumens or, as it is often alluded to, the hot toluol-benzol extraction test, is applicable to asphalts and coal-tar pitches, but is used especially in connection with the latter because other solvents, such as carbon bisulphide, are slower and more troublesome. The apparatus

* Journal of Industrial and Engineering Chemistry, Vol. 6, No. 4, April, 1914. Adopted in slightly different form, in 1916, by the Am. Soc. for Testing Materials.

for this test is shown in Fig. 101. The pitch is first dried, then it is passed through a 30-mesh sieve to remove any foreign substances. In testing materials of 5 per cent or more insoluble matter, 5 grams should be taken for the test. With lesser percentages, 10 grams should be used. The amount is weighed in a 100-c.c. beaker, and digested with about 50 c.c. of c.p. toluol on a steam bath for a period not to exceed thirty minutes. A filter cup, previously prepared, is weighed in the weighing bottle and placed in a carbon filter tube over a beaker or flask. The toluol-tar mixture is now decanted through the thimble and washed with hot c.p. toluol until cleaned,

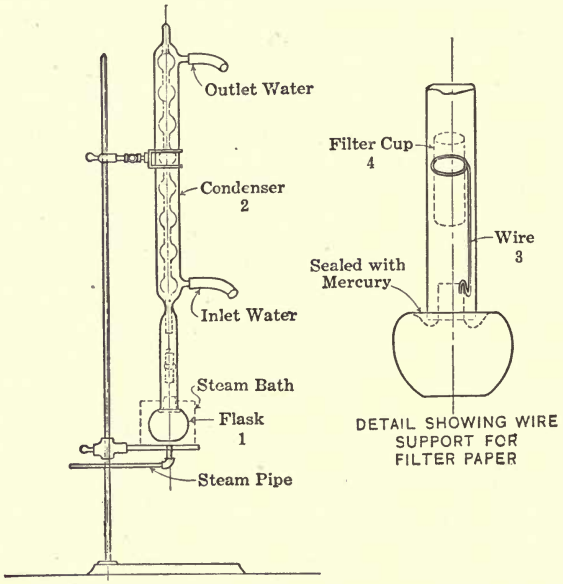


FIG. 101.—Extraction Apparatus for Free Carbon.

1. Flask. 2. Knorr extraction apparatus. 3. Copper wire. 4. Filter cup (2 sheets).

using some form of "policeman," which is unaffected by toluol, for the purpose of detaching any residue which may adhere to the beaker. The cup is finally given a washing with hot c.p. benzol and then after draining, is covered with a cap of filter paper or alundum, and placed in the extraction apparatus in which the c.p. benzol is used as solvent. The extraction is continued until the descending liquid is colorless. The thimble is then removed, the cap taken off, dried in the steam oven and weighed in the weighing bottle after cooling in the desiccator. For more detailed information regarding this test, the reader is referred to the "Journal of Indus-

trial and Engineering Chemistry," Vol. 3, No. 4, April, 1911, and Vol. 6, No. 4, April, 1914.

Ash Test. The ash test is not of great significance, and denotes whether there has been a mineral filler of any sort added to the pitch or bitumen. Normal coal-tar pitches will run between ½ and 1 per cent of ash, so that if extraneous matter is present, the ash may run above this amount. Refined asphalts, except Bermudez and Trinidad asphalt, run about ½ of 1 per cent ash.

The ash determination is made by burning to ash a 1-gram sample of the material in a weighed platinum crucible or dish of sufficient size. Heat is gently applied until the pitch or bitumen ignites, after which it is withdrawn. After the material ceases to burn, the heat is again applied until the residue is burnt free of carbon. The crucible and contents are then cooled and weighed and the ash determined.

Fixed Carbon Test. Fixed carbon, as such, does not exist in any bituminous binder, but is the amount of coke produced by burning the bitumen in a certain specified and generally accepted manner. The test is frequently used in laboratories to aid in the classification of different bituminous materials, and in some instances is of value in helping to determine their probable origin. Aside from this, the test is of no value at all, as a means for determining the quality of the material, though it is also supposed to indicate the mechanical stability and substantial nature of the bitumen. There is, however, little or nothing in the fixed carbon test, either theoretically or practically, which shows that a material containing over or under a certain definite percentage of fixed carbon is or is not suitable for waterproofing purposes. Because this is not a generally accepted view, it was deemed advisable to include a description of this test.

The test is conducted as follows: One gram of the bituminous material is placed in a platinum weighing crucible between 20 and 30 grams, between 28 and 38 mm. in height, and having a tightly fitting cover provided with a flange about 4 mm. in depth. The crucible and its contents are then heated, first, gently, and then more severely, until no smoke or flame issues between the crucible and the lid. It is then placed in the full flame of a Bunsen burner for seven minutes, holding the cover down with the end of a pair of tongs until the most volatile products have been burnt off. The crucible is supported on a platinum triangle with the bottom 6 to 8 cm. above the top of the burner. The flame should be fully 20 cm. high when burning free, and the determination should be made in a

place free from drafts. The upper surface of the cover shall burn clear, but the under surface may or may not be covered with carbon, depending on the character of the bituminous material. The crucible is removed to the desiccator, and, when cooled, shall be weighed, after which the cover shall be removed and the crucible placed in an inclined position over the Bunsen burner and ignited until nothing but ash remains. Any carbon deposited on the cover should also be burnt off. The weight of ash remaining should be deducted from the weight of the residue after the first ignition of the sample. The resulting weight is that of the fixed carbon, which should be calculated on the basis of the total weight of the sample, exclusive of mineral matter.

Paraffin Test. Paraffin is probably the best water-resisting material, but one of its adverse properties is lack of cohesiveness. Therefore its presence in a bitumen in more than moderate quantities would reduce the ductility of that bitumen and also its adhesiveness, or cementing value. Hence, it is sometimes desirable to determine the amount of paraffin present and to limit this amount depending upon the use to which the bitumen is to be put. But as all except paraffin petroleums (i.e., all semi-asphaltic and asphaltic petroleums) are known to contain less than 6 per cent. of paraffin it becomes unnecessary for practical use to determine the exact amount; first because this amount is not very injurious, and, secondly, the ductility test automatically precludes the possible presence of an excess quantity of paraffin in the asphalt. However, the subject is believed to need further investigation. The test for this material follows:

One hundred grams of the bituminous material should be distilled rapidly in a retort to a dry coke. Five grams of the distillate should then be thoroughly mixed in a 60-c.c. flask with 25 c.c. of Squibb's absolute ether. Twenty-five c.c. of Squibb's absolute alcohol should then be added, and the flask packed closely in a freezing mixture of finely crushed ice and salt for at least thirty minutes. The precipitate is then filtered out quickly with a suction pump using a No. 575 C. S. and S. 9-cm. hardened standard filter paper. The flask and precipitate are then rinsed and washed with a mixture of equal parts of Squibb's alcohol and ether, cooled to 1 deg. Fahr. (−17 deg. Cent.), until free from oil (50 c.c. of washing solution is usually sufficient). When sucked dry, the filter paper should be removed and the waxy precipitate transferred to a small glass disc and evaporated on a steam bath. The residue (paraffin) remaining on the disc is weighed, and from this weight the percentage on the original 5-gram sample is calculated.

Dimethyl Sulphate Test.* The dimethyl sulphate test is employed to detect the presence of petroleum or asphalt in coal tar. It is used either to determine the percentage mixture of asphalt with coal tar to meet certain specifications or to detect the presence of asphaltic products in coal tar as an adulterant. The test is mainly qualitative, but is valuable when even as little as 3 per cent of petroleum or asphalt products are present in the coal tar.

The equipment necessary for the dimethyl sulphate test is the same as that specified for the distillation test recommended by the American Society for Testing Materials; Proc. 1911, Vol. 11, p. 240, and adopted in 1916.

The pitch specimen is distilled and fractions taken at 518 to 572 deg. Fahr. (270 to 300 deg. Cent.), 572 to 662 deg. Fahr. (300 to 350 deg. Cent.), and 662 to 707 deg. Fahr. (350 to 375 deg. Cent.). These fractions are separately stirred and, if necessary, heated to dissolve solids which may be present.

Four cubic centimeters of distillate from each fraction are separately shaken with 6 c.c. of dimethyl sulphate ($(CH_3)_2SO_4$) in a 10-c.c. cylinder. After standing thirty minutes the resultant supernatant layer of insoluble oil, from the petroleum or asphalt, is read and calculated to its percentage by volume of the sample of distillate taken. The results are reported as follows:

Fractions.		Per Cent of Distillate.	Per Cent of Distillate Insoluble in Dimethyl Sulphate.
°F.	°C.		
518–572	270–300	.....	.....
572–662	300–350	.....	.....
662–707	350–375	.....	.....

Tests on Treated and Untreated Cement Mortar and Concrete

Many tests have been made to determine the permeability of cement mortars and concrete with and without admixtures of waterproofing materials. It is well to understand at least some of these. A brief description of the methods and the apparatus used and instructions on the performance of these tests will therefore be given. It is assumed that the reader is already acquainted with the physical properties and methods of testing the constituent materials of concrete, and that he has a general knowledge of the manipulation of

* U. S. Dept. of Agriculture, Bulletin No. 314, p. 25.

apparatus for such tests. If this be not so, any standard book on concrete may be consulted with advantage.

Standard Instructions for Permeability Tests. The following standard instructions for permeability tests on mortar waterproofed by the integral method have been used very successfully in the concrete testing laboratory of the Public Service Commission, First District, State of New York:

" Mix the mortar in accordance with the directions accompanying the waterproofing compound which is to be tested. Make several specimens to be tested after seven days and several more to be tested after twenty-eight days. In no case make fewer than eight treated specimens (total number) and eight untreated specimens, for comparison. Use extra clean, coarse sand (not Ottawa sand) for these specimens in order that the waterproofing compound may receive no assistance from silt in the sand.

" In the absence of different directions, mix the mortar to the same consistency as that of Ottawa sand mortar when mixed with 60 per cent of water above what is required for normal consistency, e.g., if 10 per cent of water is required to make Ottawa sand mortar of normal consistency, then 16 per cent of water will be required to make Ottawa sand mortar of the desired consistency. Place the mortar in the $7\frac{1}{2}$- or 8-inch pipe sections (see Fig. 102, *A*,) after it has been mixed hard with the hands for the time specified, or until a satisfactory mixture has been obtained. Specimens are then worked thoroughly into this mold with hands and trowel. Place a small amount in each mold and work it well to force out air bubbles before adding more mortar. Continue in this manner until the molds are full. The iron plates under the specimens must be thoroughly greased. Strike off the tops of specimens with a straight edge.

" Store the specimens in moist air twenty-four hours. Then brush both surfaces with a wire brush, mark, and place them in water until tested. Paint marks must not be placed on the surfaces which are to be tested. Specimens are not to be removed from the mold until after they have been tested.

" Upon removing specimens from water for testing, brush both surfaces again with a wire brush. Test under a pressure of 50 pounds per square inch for at least seven hours. If a measuring glass is used, some means must be found to prevent water from the outside from leaking into the measuring glass, since it has a tendency to follow down the outside of the outlet pipe.

" Record results at fifteen-minute intervals.

"On report show the time elapsed from application of pressure to first leakage, the average leakage for the time after specimen began to leak, and the maximum leakage for one hour. Express results in cubic centimeters per square foot per hour."

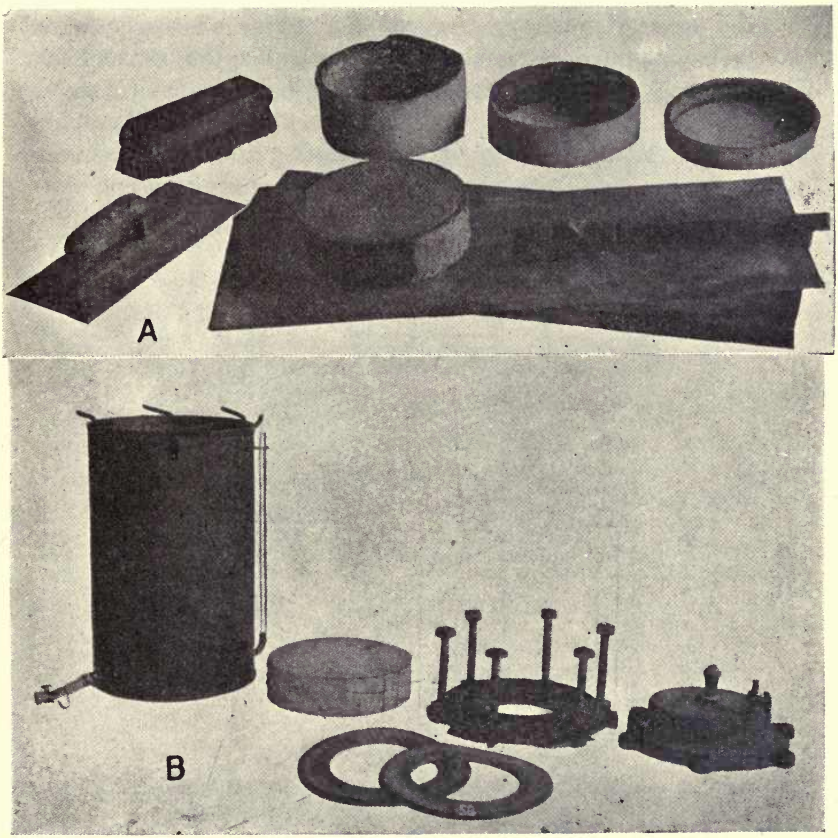


FIG. 102.

A. Permeability Molds and Test Pieces.
B. Permeability Test Piece Holder.

Description of Standard Apparatus. The apparatus* for holding the test pieces is shown in Fig. 102, *B*, in sections ready to assemble. Fig. 103 is a cross-sectional view of the test piece assembled ready for testing. *A*, *A* are rubber washers of 5-inch inside diameter and 8-inch outside diameter; *B*, *B* are cast-iron top and bottom sections

* Technologic Paper No. 3, U. S. Bureau of Standards, Dept. of Commerce and Labor.

of the holder; *C* is the test piece $7\frac{1}{2}$ inches in diameter and 1, 2 or 3 inches thick and is retained in corresponding short-length sections of $7\frac{1}{2}$-inch diameter wrought-iron pipe; *D* is the retainer in which the water passing through the test piece is caught.

The foregoing directions and apparatus have become most generally used in laboratory practice. Other methods are employed but the basic principles remain the same, that is, the measurement of the quantity of water that will come through mortar or concrete under a given static head of water. One of these methods used by Mr. Francis M. McCullough, B.S., in testing the permeability of

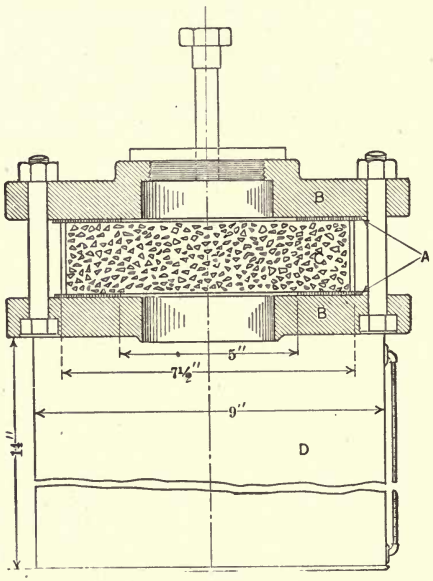


Fig. 103.—Cross-section of Apparatus for Holding Permeability Test Pieces.

waterproofed concrete at the University of Wisconsin,* is exemplary and the following is a description.

Method of Testing Permeability of Waterproofed Concrete. The apparatus used by Mr. McCullough for testing the permeability of concrete consists essentially of eight 6-inch pipes filled with concrete and a pipe system connected with air and water reservoirs. Fig. 104, *A*, shows in detail the mold and attached casting and Fig. 104, *B*, is a general drawing of the pipe system for four specimens, the apparatus for the remaining four specimens being the same as shown.

* Bulletin No. 336, University of Wisconsin.

The molds are 6-inch wrought-iron pipe, $12\frac{1}{2}$ inches long, with a cast-iron flange screwed to the upper end. In order to prevent the passage of water between the pipe and the cement lining ten or twelve V-shaped grooves were cut in each pipe, each groove extending around the inner surface of the pipe.

This flanged pipe was attached to the casting by means of six eyebolts. A $\frac{3}{4}$-inch pipe, 4 feet 6 inches long, was screwed into this casting. Each of these $\frac{3}{4}$-inch pipes was jointed to the main pipe, which, in turn, connected with the water main and with the air reservoirs. The shut-off globe valves for water and air are shown on the pipes connecting the main pipe with the water main and with

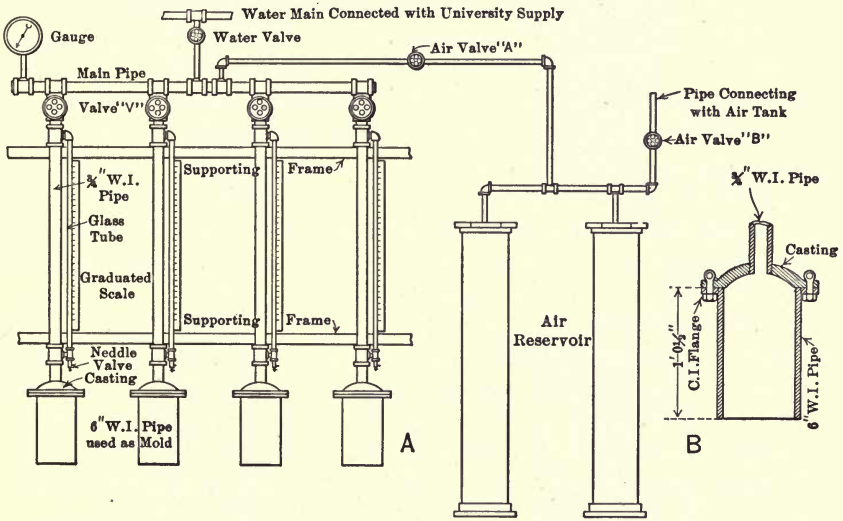


FIG. 104.

A. Apparatus for Testing Permeability of Concrete.
B. Section of Mold and Casting.

the air reservoirs. The cast-iron cylinders, $6\frac{1}{2}$ inches in diameter and 4 feet 8 inches long, formed the air reservoirs. They were connected with a large air tank, not shown, by means of the pipe shown in Fig. 104, *B*, a shut-off globe valve being placed between the air tank and air reservoirs.

A glass tube and attached scale graduated to hundredths of a foot were fastened to each $\frac{3}{4}$-inch pipe in order to obtain the water level in the pipe. The globe valve *V* was used in order to disconnect any specimen proving defective. The $\frac{3}{4}$-inch pipe and glass tube were drained by means of the needle valve. A gauge registered the air pressure.

The specimens were securely bolted to the castings, a rubber gasket being used between the finished faces of flange and casting. With the air valve *A* closed and the air valve *B* opened, air was admitted to the reservoirs until sufficient pressure was obtained. The water valve was opened and water was allowed to fill the $\frac{3}{4}$-inch tubes. Care was taken that the pressure did not exceed that used in the test, this being regulated by opening the needle valves. Air valve *B* was closed and air valve *A* connecting with the air reservoirs was opened, thus subjecting the specimens to pressure.

The rate of flow of the water through the concrete was obtained by noting the scale readings and the time. Pressures were also noted, but they showed very little decrease as the volume of the air reservoirs was very large compared to the volume of the $\frac{3}{4}$-inch pipes. No readings were taken for five minutes after the pressure was on. As the rate of flow rapidly decreased readings were taken at intervals of ten or fifteen minutes for the first few hours and then at intervals gradually increasing from two to eight hours. The bottoms of the specimens were frequently examined and any dampness noted.

When readings are taken all joints should be carefully examined and any leaks noted, and the effect of this leakage eliminated as much as possible in reducing the data.

The proportions by volume of the concrete were 1 : 3 : 5, the required amount of materials being weighed. No attempt was made to secure a waterproof concrete by proper proportioning. On the contrary, a lean mixture was desirable in order to bring out the waterproofing qualities of the compounds. Local stone and sand and Portland cement were used. The stone was a rather sandy limestone, while the sand was of the fine bank variety.

Results of Permeability Tests on Waterproofed Concrete. We will now consider the results of these tests on concrete treated with a few waterproofing compounds. These compounds may be classified according to the manner in which they were used in the tests.

(1) Compounds applied to the surface of the concrete, which in themselves may be sub-divided into three classes:

- (*a*) Compounds which are applied as surface paints.
- (*b*) Compounds which were applied in layers to form a membrane.
- (*c*) Compounds which were applied as a surface coating in the form of a thick layer.

(2) Foreign ingredients added to the body of the concrete.

(3) Foreign ingredients added to the mortar coating.

(4) Plain cement mortar.

Different methods, as illustrated in Fig. 105, were used in finishing the upper surface of the specimens, depending upon the kind of waterproofing compound used. As shown in Fig. 105, *A* and *B*, the concrete was finished flush with the top of the pipe, the upper surface of the concrete being well troweled. Before troweling, the specimens were allowed to stand a half hour in order that the free water on the concrete might be absorbed. The cement lining extends to the top of the concrete in *B*, while in *A* it is cut off $\frac{1}{4}$ inch below. In the specimens that were coated with mortar, as shown in Fig. 105, *C* and *D*, the surface of the concrete was $\frac{3}{4}$ inch below the top of the

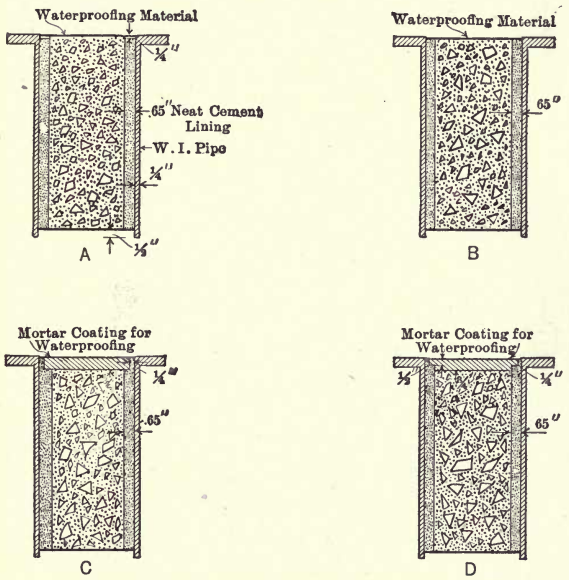


FIG. 105.—Methods of Finishing Upper Surface of Concrete Specimens.

pipe. After the concrete had absorbed the standing water the mortar top was added, the surface of the concrete and the mortar being thoroughly troweled. In applying all surface preparations, care was taken to secure a dry, clean surface and to have the preparation well brushed in. The water pressure varied from 20 pounds to 40 pounds per square inch applied continuously from three to seven days.

In all cases except those in which the compounds were applied in the form of a membrane, the results were variable. The materials used were more or less reliable but the results obtained were not often enough satisfactory to establish a single superior compound.

In most cases where a material withstood the low pressure it failed completely under the higher pressure. None withstood either pressure absolutely without absorption or percolation, with the

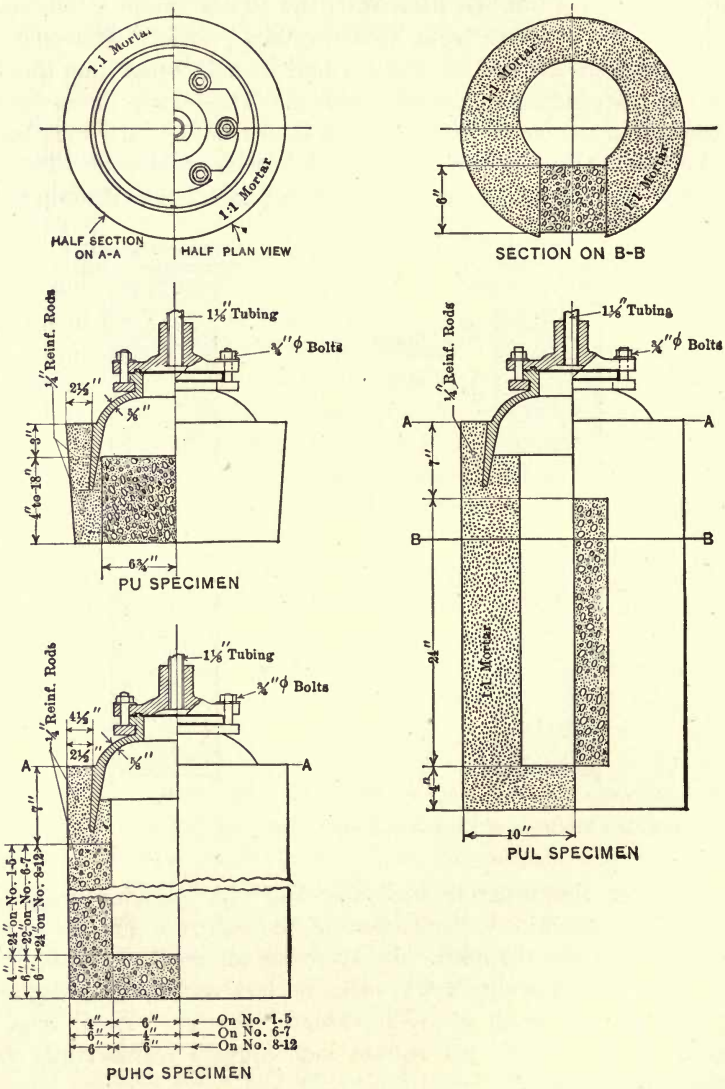


FIG. 106.—Types of Permeability Specimens.

one exception noted above. Similar tests made on ¾-inch plain cement mortar of proportions 1 : 1½ applied to the concrete (Fig. 105, *C*), proved two facts: (1) that plain mortar can be made rea-

sonably watertight; (2) that some of the above compounds, such as the foreign ingredients added to the mortar coating, are also reasonably effective and warrant their use under certain conditions.

Results of Permeability Tests on Plain Concrete. Still another method for testing the permeability of mortar and concrete, though only occasionally used, is worth noting. In an elaborate series of permeability tests,* in which machine-mixed concrete and large specimens having a prescribed volume of concrete were used without

FIG. 107.—Longitudinal Sections of "PU" and "PUHC" Permeability Specimens.

any waterproofing added to them, many valuable facts are made patent. The forms of specimens are shown in Figs. 106 and 107. In molding these test pieces, both mortar shell and concrete core were cast at the same time. The area of the core is 1 square foot, hence the leakages read were in terms of this unit.

The results of these permeability tests, made on 294 gravel-concrete specimens, agree very well with similar tests made by other experimenters. Of the above number 88 were of 1 : $1\frac{1}{2}$: 3 and 67 of 1 : 2 : 4 proportions by volume; 98 were of 1 : 3 : 9 proportions by weight.

* Journal of the Western Society of Engineers, November, 1914, Vol. 19, No. 9.

None of the concretes tested was absolutely watertight if we consider continuous flow into the specimen as proof of permeability, but the majority of mixes were so impervious that no visible evidence of flow appeared. For most purposes such mixes can be considered watertight.

The visibility of dampness on the bottom of the specimens increased with the humidity of the air and the non-homogeneity of the concrete. The minimum rate of flow for which leakage was indicated was 0.00011 gallon (approximately .42 c.c.) per square foot per hour.

In tests of nearly all of the properly made mixes of 1 : $2\frac{1}{4}$: $4\frac{3}{4}$ proportions, or richer, the rate of flow for a fifty-hour period was less than 0.0001 gallon (approximately .38 c.c.) per square foot per hour under a pressure of 40 pounds per square inch.

Through increasing the fineness of the cement a reduction in the rate of flow and a considerable increase in the strength of a 1 : 3 : 6 mix were secured.

By grading the sand and gravel in accordance with Fuller's curve it was possible to obtain practically watertight concrete of 1 : 3 : 6 proportions under pressures less than 40 pounds per square inch. To secure such results, however, requires great care and careful supervision in mixing, in determining the proper consistency, in placing, and in curing the concrete.

In the proportioning of such materials as these, volumetric analysis coupled with a determination of the density and air voids yields very valuable information concerning the best proportions of sand and gravel for a given proportion of cement. If proportions must be selected arbitrarily, a 1 : $1\frac{1}{2}$: 3 mix, by volume, is very impervious. It should be remembered, however, that the volume changes in rich mixtures due to alternate wetting and drying are much greater than for lean mixtures. Consequently due attention must be given to the provision of expansion joints and reinforcement in structures made of rich mixtures.

The use of the proper amount of water necessary to produce a medium or mushy consistency is one of the most important conditions in securing impervious concrete, especially when lean mixtures are used. Dry mixtures cannot be sufficiently compacted in the molds and are more difficult to cure properly than the mushy mixtures. Although the use of a wet consistency does not materially affect the imperviousness of very rich mixes, such as 1 : $1\frac{1}{2}$: 3, it greatly increases the flow through a lean mix.

For lean mixes made from damp sand, it seems advisable to mix

TABLE X.—RELATIVE ABRASION OF CONCRETE FLOOR HARDENERS—*Continued*

Specimen No.	Composition.	Proportions.†	Age, Days.	Loss in Weight. Grams.	Loss in Thickness. Inch.	Ratio of Loss in Weight to Loss in Weight of Corresponding Plain Specimen.		Ratio of Loss in Thickness to Loss in Thickness of Corresponding Plain Specimen.	
26	Sand : cement*.....	1 : 1	28	4.0	0.038				
	Sand : cement (1 : 1) mixed with:								
27	Calcium chloride solution : water	1 : 10	7	4.9	0.044	1.12		1.26	
28	Plain water.....	Proper consistency	7	4.4	0.035		Ave. 1.04		Ave. 1.12
29	Calcium chloride solution : water	1 : 10	7	3.9	0.033	0.95		0.97	
30	Plain water.....	Proper consistency	7	4.1	0.034				
	Sand : cement (1 : 1) mixed with:								
31	Calcium chloride solution : water	1 : 10	28	3.7	0.028	1.48		1.4	
32	Plain water.....	Proper consistency	28	2.5	0.020		1.30		1.41
33	Calcium chloride solution : water	1 : 10	28	3.8	0.034	1.12		1.42	
34	Plain water.....	Proper consistency	28	3.4	0.024				
	Sand : cement : grit (1 : 1 : 1) mixed with:								
35	Calcium chloride solution : water	1 : 10	7	3.5	0.034	0.92		0.587	
36	Plain water.....	Proper consistency	7	3.8	0.058		0.917		0.742
37	Calcium chloride solution : water	1 : 10	7	3.2	0.026	0.914		0.897	
38	Plain water.....	Proper consistency	7	3.5	0.029				
	Sand : cement : grit (1 : 1 : 1) mixed with:								
39	Calcium chloride solution : water	1 : 10	28	3.5	0.027	0.945		1.039	
40	Plain water.....	Proper consistency	28	3.7	0.026		0.903		0.975
41	Calcium chloride solution : water	1 : 10	28	3.1	0.030	0.861		0.910	
42	Plain water.....	Proper consistency	28	3.6	0.033				

* Refers to Portland cement in all cases.
† All liquids proportioned by volume; other proportions by weight.

of a cement floor are almost directly proportional to the amount of troweling work put upon it without crazing the surface.

From a study of numerous applications, of mineral, metal, and liquid floor hardeners, and a review of Table X, the liquids, in general, seem to give much better service, being also more easily applied, and when wear develops, may be as easily reapplied.

The abrasion tests,* results of which are given in Table X, were made on an abrasion apparatus consisting of a 16-inch cast-iron disc, revolving at the rate of 42 revolutions per minute. Fine sand was fed upon this disc by means of two funnels each placed 6 inches from the center of the disc. The size of the opening at the bottom of each funnel was regulated by means of a metal slide. The sand used was fine beach sand graded so that all particles passed a No. 50 sieve and were retained on a No. 100 sieve. Two test samples placed opposite each other, were held down upon this disc by being placed in weighted cylindrical holders. This machine was so devised that these holders could hold the center of the specimens always on the circumference of a 12-inch circle.

Mortar cylinders 2 inches in diameter and $1\frac{1}{2}$ inches high were used as test samples. A good grade of Portland cement and Long Island bank sand were used throughout. No attempt was made to surface a sample with a thin coating of any compound. Wherever specific directions were furnished with a compound, these directions were closely adhered to. Eight cylinders were made with each batch of mortar to be tested, four cylinders containing the compound to be tested and the remaining four were of plain mortar. Two treated and two untreated specimens were tested at seven days and the remaining specimens were tested at twenty-eight days.

All specimens were dried until they showed no further loss in weight. The specimens were then carefully weighed and calipered. Measurements were taken by micrometer calipers at five points—the center and at four points equally distant on the circumference. The cylinders were ground in groups of two—one plain and one treated specimen—for thirty minutes. Approximately 450 grams of sand were used in each test. The samples were then again weighed and calipered. In determining the loss in thickness of each cylinder, the cylinder was considered as being composed of four triangles, the center being the common vertex. For this reason, the center measurement was given a weight of four and each measurement on the circumference given a weight of two.

* Tests made in Physical Laboratory of the Public Service Commission, 1st Dist., New York, 1917.

The results noted in the table are undoubtedly representative of average 1 : 2 : 4 concrete.

The most interesting fact disclosed is that the absorption of concrete is very little affected by the greater or less absorptiveness of the various large aggregates except cinders (see Table I). In other words the absorption of concrete is dependent mainly on the matrix.

Test on Concrete Floor Hardeners

Concrete floor hardeners are applied to floors for the purpose of making them dustproof and waterproof by surface densification. The term " floor hardener " is a misnomer, as most of the materials used, with the exception of carborundum and like materials, do not add to the hardness of the floor, but give merely a better wearing floor due to other properties than hardening properties. Abrasive tests described below on these materials conclusively prove the fact that they do not add hardness to a cement floor. However, these materials are not confined to minerals or metals only, but may be liquids, with bases of wax, oil, varnish, etc., these generally being applied to the finished floor. The mineral or metal materials are sometimes incorporated in the concrete or cement mortar before these have finally set, but in most instances, they are merely dusted on the surface and troweled in. This gives a floor surface with a more or less thin layer which may wear through, leaving the floor practically in the same condition as an untreated cement floor. The effect of the more successful floor hardeners is to produce a floor really more dust proof, due to the smooth surface of the finished floor. This naturally implies a floor with a minimum of surface voids and crevices to hold dust and moisture, and also little liability to raveling. However, when a hard material like carborundum is used, a hard floor and not a smooth floor is obtained. This type of floor presents a rough, coarse surface, and is in fact a very dusty one. From the point of view of floor hardeners, the best dustproof floor is a terrazzo floor (mainly used in public buildings), in which the wearing surface is largely the coarse aggregate used in the floor. This is ground by hand or by machine to present a maximum wearing surface and reduce the mortar of the wearing surface to a minimum.

The efficiency of some of the floor hardeners is often less due to the character of the hardener than to the extra work required in troweling the treated floor. In fact, the smoothness and hardness

TABLE X.—RELATIVE ABRASION OF CONCRETE FLOOR HARDENERS

Specimen No.	Composition.	Proportions.‡	Age, Days.	Loss in Weight. Grams.	Loss in Thickness. Inch.	Ratio of Loss in Weight to Loss in Weight of Corresponding Plain Specimen.		Ratio of Loss in Thickness to Loss in Thickness of Corresponding Plain Specimen.	
1	Powdered cast-iron : cement*	1 : 1	7	18.7	0.129	3.4		2.94	
2	Sand : cement	1 : 1	7	5.5	0.044		Ave. 4.15		Ave. 3.41
3	Powdered cast-iron : cement	1 : 1	7	19.6	0.151	4.9		3.88	
4	Sand : cement	1 : 1	7	4.0	0.039				
5	Powdered cast-iron : cement	1 : 1	28	10.8	0.086	2.64		1.69	
6	Sand : cement	1 : 1	28	4.1	0.039		2.85		1.68
7	Powdered cast-iron : cement	1 : 1	28	11.3	0.055	3.06		1.67	
8	Sand : cement	1 : 1	28	3.7	0.033				
9	Powdered iron : cement	1 : 1	7	12.6	0.092	2.52		1.84	
10	Sand : cement	1 : 1	7	5.0	0.050		2.48		1.84
11	Powdered iron : cement	1 : 1	7	16.8	0.111	2.44		1.85	
12	Sand : cement	1 : 1	7	6.9	0.060				
13	Powdered iron : cement	1 : 1	28	7.0	0.055	1.63		1.22	
14	Sand : cement	1 : 1	28	4.3	0.045		1.52		1.34
15	Powdered iron : cement	1 : 1	28	5.9	0.060	1.41		1.46	
16	Sand : cement	1 : 1	28	4.2	0.041				
17	Iron oxide : cement†	1 : 1	7	34.1	0.278	6.69		5.35	
18	Sand : cement	1 : 1	7	5.1	0.052				
19	Granular carborundum : cement	1 : 1	7	1.3	0.003	0.228		0.071	
20	Sand : cement	1 : 1	7	5.7	0.042		0.280		0.087
21	Granular carborundum : cement	1 : 1	7	1.4	0.003	0.333		0.103	
22	Sand : cement	1 : 1	7	4.2	0.029				
23	Granular carborundum : cement	1 : 1	28	0.8	0.006	0.250		0.2317	
24	Sand : cement	1 : 1	28	3.2	0.026		0.288		0.181
25	Granular carborundum : cement	1 : 1	28	1.3	0.005	0.325		0.132	

* Refers to Portland cement in all cases.
† "Iron oxide" consists of iron filings mixed with about 2 per cent salammoniac to augment oxidation process.
‡ All liquids proportioned by volume; other proportions by weight.

TABLE X.—RELATIVE ABRASION OF CONCRETE FLOOR HARDENERS—*Continued*

Specimen No.	Composition.	Proportions.†	Age, Days.	Loss in Weight. Grams.	Loss in Thickness. Inch.	Ratio of Loss in Weight to Loss in Weight of Corresponding Plain Specimen.		Ratio of Loss in Thickness to Loss in Thickness of Corresponding Plain Specimen.	
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27	Calcium chloride solution : water	1 : 10	7	4.9	0.044	1.12		1.26	
28	Plain water.....	Proper consistency	7	4.4	0.035		Ave. 1.04		Ave. 1.12
29	Calcium chloride solution : water	1 : 10	7	3.9	0.033	0.95		0.97	
30	Plain water.....	Proper consistency	7	4.1	0.034				
	Sand : cement (1 : 1) mixed with:								
31	Calcium chloride solution : water	1 : 10	28	3.7	0.028	1.48		1.4	
32	Plain water.....	Proper consistency	28	2.5	0.020		1.30		1.41
33	Calcium chloride solution : water	1 : 10	28	3.8	0.034	1.12		1.42	
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36	Plain water.....	Proper consistency	7	3.8	0.058		0.917		0.742
37	Calcium chloride solution : water	1 : 10	7	3.2	0.026	0.914		0.897	
38	Plain water.....	Proper consistency	7	3.5	0.029				
	Sand : cement : grit (1 : 1 : 1) mixed with:								
39	Calcium chloride solution : water	1 : 10	28	3.5	0.027	0.945		1.039	
40	Plain water.....	Proper consistency	28	3.7	0.026		0.903		0.975
41	Calcium chloride solution : water	1 : 10	28	3.1	0.030	0.861		0.910	
42	Plain water.....	Proper consistency	28	3.6	0.033				

* Refers to Portland cement in all cases.
† All liquids proportioned by volume; other proportions by weight.

of a cement floor are almost directly proportional to the amount of troweling work put upon it without crazing the surface.

From a study of numerous applications, of mineral, metal, and liquid floor hardeners, and a review of Table X, the liquids, in general, seem to give much better service, being also more easily applied, and when wear develops, may be as easily reapplied.

The abrasion tests,* results of which are given in Table X, were made on an abrasion apparatus consisting of a 16-inch cast-iron disc, revolving at the rate of 42 revolutions per minute. Fine sand was fed upon this disc by means of two funnels each placed 6 inches from the center of the disc. The size of the opening at the bottom of each funnel was regulated by means of a metal slide. The sand used was fine beach sand graded so that all particles passed a No. 50 sieve and were retained on a No. 100 sieve. Two test samples placed opposite each other, were held down upon this disc by being placed in weighted cylindrical holders. This machine was so devised that these holders could hold the center of the specimens always on the circumference of a 12-inch circle.

Mortar cylinders 2 inches in diameter and $1\frac{1}{2}$ inches high were used as test samples. A good grade of Portland cement and Long Island bank sand were used throughout. No attempt was made to surface a sample with a thin coating of any compound. Wherever specific directions were furnished with a compound, these directions were closely adhered to. Eight cylinders were made with each batch of mortar to be tested, four cylinders containing the compound to be tested and the remaining four were of plain mortar. Two treated and two untreated specimens were tested at seven days and the remaining specimens were tested at twenty-eight days.

All specimens were dried until they showed no further loss in weight. The specimens were then carefully weighed and calipered. Measurements were taken by micrometer calipers at five points—the center and at four points equally distant on the circumference. The cylinders were ground in groups of two—one plain and one treated specimen—for thirty minutes. Approximately 450 grams of sand were used in each test. The samples were then again weighed and calipered. In determining the loss in thickness of each cylinder, the cylinder was considered as being composed of four triangles, the center being the common vertex. For this reason, the center measurement was given a weight of four and each measurement on the circumference given a weight of two.

* Tests made in Physical Laboratory of the Public Service Commission, 1st Dist., New York, 1917.

From a detailed review of Table X the following facts are noted: Iron filings injure the wearing qualities of a concrete floor. Iron filings treated with salammoniac cause a mortar to fail completely. These results, however, are not regarded as conclusive.

A 4 per cent solution of calcium chloride will rapidly increase the hardness and tensile strength of a mortar during the first seven days. This advantage however is overcome after twenty-eight days.

Carborundum greatly increases the hardness of a floor. Very little wear occurs after the top skin of cement has been ground off.

A coarse sand aggregate or an aggregate of sand and grits gives a more wear-resistant mortar than that made of finer sand.

Comparison of Melting-points of Bitumens.* Ten samples of asphalt were tested according to the requirements of each of the first three of the following standard methods for finding the melting-point of bituminous material and twenty samples according to the fourth method (but not tabulated below).

(1) C. I. Robinson, or the Ring and Ball Method. (R. and B. Method).

(2) Cube-in-water Method (C.-in-W. Method).

(3) Kraemer and Sarnow Method (K. and S. Method).

(4) Mabery-Sieplein Method (M.-S. Method).

A careful perusal of the description of these methods, given on page 197 will facilitate understanding the purpose and results of this test, especially because of lack of uniformity of opinion by chemists as to preference, superiority or correctness of any of them.

From the values in Table XI it is evident that the Cube-in-water Method registers a comparatively high melting-point and cannot be altogether reliable for the reason that the specific gravity of the bitumen enters as a factor in these figures. It is also evident that the Ring and Ball and Kraemer and Sarnow Methods are probably more correct, because of close agreement of the results and because these are independent of the specific gravity of the bitumen.

A similar but more extended series of tests† was made on various asphalts and pitches, to determine the conversion factors between

* This and the following eighteen tests are reprinted from a paper by the author in the N. Y. Municipal Engineers' Journal, Vol. 3, No. 7, September, 1917. Attention is directed here to the fact that the following tests are far from being exhaustive or complete either in technique or interpretation of results. But partly for the reason explained in the forepart of this chapter and partly because of their suggestive value it was considered warrentable to reprint them here.

† These tests were made in the Chemical Laboratory of the Public Service Commission for the First District, State of N. Y.; R. L. Oberholser, Chief Chemist.

the four methods. From the results thus obtained, and the tabulated values given above, Table XII was constructed. By means of this table the known melting point of a bitumen by one method is readily converted to an equivalent value by another method.

TABLE XI.—COMPARATIVE MELTING-POINTS OF BITUMEN

Asphalt Sample, Number.	Ball-and-ring Method, Degrees Fahrenheit.	Difference Between Ball-and-ring and Cube-in Water Methods.	Cube-in-Water Method, Degrees Fahrenheit.	Difference Between Cube-in-Water and Kraemer and Sarnow Methods.	Kraemer and Sarnow Method, Degrees Fahrenheit.
1.....	169	31	200	33	167
2.....	109	30	139	37	102
3.....	151	27	178	29	149
4.....	129	24	153	32	121
5.....	122	30	152	33	119
6.....	124	26	150	30	120
7.....	134	25	159	33	126
8.....	131	29	160	40	120
9.....	127	31	158	32	126
10.....	139	27	166	37	129

TABLE XII.—CONVERSION OF MELTING-POINTS OF BITUMEN

Method Given—Values in Degrees Fahrenheit.	To Transform to			
	Ball-and-ring Method.	Kraemer and Sarnow Method.	Mabery-Sieplein Method.	Cube-in-Water Method.
Ball-and-ring.....	.....	Add 5	Subtract 20	Subtract 30
Kraemer and Sarnow..	Subtract 5	.....	Subtract 25	Subtract 35
Mabery-Sieplein.....	Add 20	Add 25	.....	Subtract 15
Cube-in-water.....	Add 30	Add 35	Add 15	.....

Effect of Heat on Various Pitches Mixed with Linseed Oil.* A mixture of pitch and linseed oil is often used as a pipe-coating, and as a coating for steel and cast-iron tunnel segments. In applying this compound, it is found necessary to heat it in open tanks for very long periods. Hence, the question: what effect has such heating upon the mixture? To learn the answer to this question, a seventy-two hour heating test was made with three grades of pitch, the results of which are given in Table XIII.

* Test made in Chemical Laboratory of Public Service Commission for the First District, State of N. Y.; R. F. Oberholser, Chief Chemist.

TABLE XIII.—EFFECT OF HEAT ON MIXTURES OF COAL-TAR PITCH AND LINSEED OIL

Kind of Pitch.	Pitch Prior to Heating.				After 24 Hours Heating.			
	Per Cent of Raw Linseed-oil Mixed with Pitch.	Softening-point (Degrees Fahrenheit).	Melting-point Degrees (Fahrenheit Cube-in-Water).	Free Carbon (Per Cent).	Softening-point (Degrees Fahrenheit).	Melting-point (Degrees Fahrenheit).	Free Carbon (Per Cent).	Loss after Heating (Per Cent).
Soft	5	...	...	.....	84	108	29.9	3.80
	None	76	107	29.5	94	120	30.9	3.36
Medium	5	...	...	.....	104	136	30.9	5.99
	None	90	123	29.9	106	138	30.8	3.08
Hard	5	...	...	.....	120	152	31.3	2.70
	None	110	144	29.6	135	172	32.1	4.09

Kind of Pitch.	After 48 Hours Heating.				After 72 Hours Heating.			
	Softening-point (Degrees Fahrenheit).	Melting-point (Degrees Fahrenheit).	Free Carbon (Per Cent).	Loss after Heating (Per Cent).	Softening-point (Degrees Fahrenheit).	Melting-point (Degrees Fahrenheit.)	Free Carbon (Per Cent).	Loss after Heating (Per Cent).
Soft	92	118	30.4	5.79	102	138	31.5	9.22
	106	132	31.5	6.55	117	150	34.3	10.10
Medium	121	154	31.4	8.34	145	180	32.9	11.50
	130	162	33.6	44.4	138	170	35.4	4.97
Hard	136	178	32.7	3.24	150	188	33.5	5.68
	154	194	34.9	7.47	168	208	36.3	10.85

Straight-run coal-tar pitch and raw linseed oil of good quality were used in this test. The melting-point was determined by the Cube-in-water Method.

This test discloses the fact that prolonged heating of pitch even when mixed with linseed oil, is injurious, as shown by the amount of oil evaporated, and the great rise in melting-point.

Hence it is imperative not to subject this coating material to continuous heat, but if this becomes unavoidable, the tank must be frequently replenished with new material.

Flowing and Bonding Properties of Pitch Containing Small Quantities of Asphalt or Linseed Oil. To obviate the danger and nuisance of using hot coal-tar pitch for waterproofing by the membrane method under compressed air, tests were made to determine the flowing and bonding properties of different melting-point pitches mixed with either 5 per cent of raw linseed oil or 5 per cent of different melting-point asphalts. These additions were made in an effort to increase the fluidity of the pitch somewhat without reducing its "substantiality" and to avoid the necessity of heating it on the work during application. These additions had the desirable effect of lowering the melting-point of the pitch about 10 deg. Fahr. (5.5 deg. Cent.) without increasing its hardness.

Four pitches were tested having the following melting-points: 75, 85, 95 and 105 deg. Fahr. (24, 29.5, 35 and 40.5 deg. Cent. respectively). (Cube-in-water Method.)

The three asphalts used to make the 5 per cent additions had the following melting-points: 107, 154 and 182 deg. Fahr. (42, 68 and 83 deg. Cent.). (Cube-in-water Method.)

The oil used was a good quality raw linseed oil.

Sixteen samples of pitch were weighed out in pint cans and each set of four of equal melting-point received an addition of 5 per cent by weight of one of the three different asphalts or the oil. These were then heated, thoroughly stirred, and allowed to cool to about 75 deg. Fahr. (24 deg. Cent.) which was approximately the temperature of the compressed air chamber under about 21 pounds pressure. On reaching this temperature each sample was troweled onto the surface of pieces of treated fabric until a 3-ply membrane was built up on planed boards as a ground work. None of the pitches was fluid enough to be mopped on, hence the troweling. The boards were then inclined at an angle of 45 degrees for seventy-two hours to compare the relative amount of sliding of each membrane. Table XIV shows the results obtained from the various mixes.

Specimens Nos. 2 and 5 appear to be best suited for the purpose, because at the temperature under which they will be used, they are both more substantial and workable than the others. Finally, since the admixture of linseed oil greatly increases the cost of the product, the one (No. 5) with an admixture of asphalt is to be preferred.

Effect of Asbestos Filler on the Physical Properties of Bitumen.* The purpose of this test was to determine whether any real benefit

* Test made in Chemical Laboratory of the Public Service Commission for the First District, State of New York, R. L. Oberholser, Chief Chemist.

TABLE XIV.—FLOWING AND BONDING PROPERTIES OF PITCH CONTAINING ASPHALT OR LINSEED OIL

Specimen No.	Melting-point of Pitches Used (Cube-in-water Method) Degrees Fahrenheit.	Material Added (5 Per Cent by Weight in All Cases).	Condition of Flow from Container at 75 Degrees Fahrenheit.	Worked under Trowel in Making 3-Ply Membrane Samples at 75 Degrees Fahrenheit.	Bond between Plies.	Amount of Sliding in 72 Hours on Board Inclined 45 Degrees.
1	75	Raw linseed-oil	Viscosity apparent	Easily	Fairly good	Slid completely off
2	85	Raw linseed-oil	Increased viscosity	Not so easily	Fairly good	Slid completely off
3	95	Raw linseed-oil	Plastic	With difficulty	Good	Slid completely off
4	105	Raw linseed-oil	Less plastic	With great difficulty	Very good	Slid completely off
5	75	107-degree melting-point asphalt	Increased viscosity	With difficulty	Fairly good	Slid completely off
6	85	107-degree melting-point asphalt	Plastic	With great difficulty	Good	Did not slide
7	95	107-degree melting-point asphalt	Less plastic	With greatest difficulty	Very good	Did not slide
8	105	107-degree melting-point asphalt	Plastic	Unworkable	No test	Did not slide
9	75	154-degree melting-point asphalt	Same as No. 5	Same as No. 5	Fairly good	Did not slide
10	85	154-degree melting-point asphalt	Same as No. 6	Same as No. 6	Good	Did not slide
11	95	154-degree melting-point asphalt	Same as No. 7	Same as No. 7	Very good	Did not slide
12	105	154-degree melting-point asphalt	Same as No. 8	Same as No. 8	No test	Did not slide
13–16	75–105	182-degree melting-point asphalt	Specimens were similar in all respects to Nos. 9, 10, 11 and 12, respectively			

accrues to waterproofing asphalt by the incorporation of asbestos of the shredded or fibrous variety, as was the practice on some of the subway work in New York City.

In preparing the specimens the bitumen was heated until liquefied and the various amounts of asbestos added and stirred until the mixture was a homogeneous mass. Table XV shows the results of the test.

TABLE XV.—EFFECT OF INCORPORATING ASBESTOS FIBER IN BITUMEN

Specimen Number.	Contents, Per Cent.			Ductility at 32 Degrees Fahrenheit.	Ductility at 62 Degrees Fahrenheit.	Ductility at 77 Degrees Fahrenheit.	Melting-point Kraemer and Sarnow Method, Degrees Fahrenheit.
	Pitch.	Asphalt.	Asbestos.				
1.....	100	.....	0	...	..	35	100
2.....	99½	.....	½	1½	13	17	110
3.....	99	.....	1	1	11	16	113
4.....	98½	.....	1½	3	10	7	119
5.....	98	.....	2	1½	8	13	140
6.....	97	.....	3	2	8	7	119
7.....	.....	100	0	...	..	20	126
8.....	.....	99½	½	3	7	10	130
9.....	.....	99	1	4	7	11	128
10.....	.....	98½	1½	1	8	13	165
11.....	.....	98	2	2	8	11	154
12.....	.....	97	3	2	9	10	143

The most evident conclusions from this test are, that due to the presence of the asbestos the ductility of the bitumen is considerably decreased and the melting-point is increased. The former fact indicates that the mixed bitumen would not hold together in the form of a thin coating as well as the pure bitumen, while the latter indicates that the mixed bitumen would flow with greater diffculty than the pure bitumen at the same temperature.

Ductility of Asphalt Containing Coal-tar Pitch. The purpose of this test is to determine the effect on the ductility of asphalt of the addition of coal-tar pitch in various percentages. Both the asphalt and the pitch were of the grade regularly used in waterproofing the dual subways in New York.

The melting-point of the pitch was about 116 deg. Fahr. (47 deg. Cent.) by the cube-in-water method, and the asphalt about 120 deg. Fahr. (49 deg. Cent.) by the Kraemer and Sarnow method.

Starting with the pure asphalt in a molten condition the mixtures were made by adding the pitch in increments of 5 per cent by weight. The specimens were then tested and gave the following results: The melting-points of the mixtures showed a decided but not constant increase with increase of pitch. The penetration of the mixtures showed an almost constant decrease and at proportions between 25 and 40 per cent of asphalt the penetration approached zero. The addition of 30 to 40 per cent of pitch to the asphalt reduced the ductility of the mixture to zero, while even as little as 5 per cent reduced the asphalt's ductility from more than 100 to 30 or 40 cm. It seems, therefore, inadvisable to mix coal-tar pitch and asphalt when this is intended for waterproofing by the membrane system. It may, though, be good as a waterproof or dampproof surface coating on masonry suited for its application, or as a roof flashing compound. A waterproofing membrane must be elastic and ductile to a reasonable degree to avoid cracking in conjunction with the structure it surrounds. Mixing these two materials tends to vitiate this by giving the product the property of "shortness," or lack of ductility.

It should be remembered, however, that inferior grades of pitch might even have a deleterious effect on the asphalt or vice versa.

Effect of Temperature on Penetration and Ductility of Asphalt and Coal-tar Pitch. The penetration and ductilities noted in these tests were made with the Dow penetrometer and tensometer, both standard testing machines used in asphalt laboratories.

Fig. 108, which is quite self-explanatory, shows that according to penetration the coal-tar pitch, though of lower melting-point, and tested in both pure and mastic forms, is harder at low temperatures and softer at high temperatures than the asphalt; also that the asphalt has a wider temperature range, that is, the asphalt is less affected for a given temperature change and softens more slowly than coal-tar pitch.

The curves in Figs. 109 and 110 show the relative penetration and ductility of asphalt and coal-tar pitch whose melting-points are practically equal, as determined by the Kraemer and Sarnow method.

From a study of the penetration curves the following facts may be noted:

(1) The asphalt and its mastics are softer than coal-tar pitch between the approximate limits of 40 and 90 deg. Fahr. (4.5 and 32 deg. Cent.).

TABLE XVI.—PROPERTIES OF MASTICS

Character of Test.	Proportions. By Weight— 4 Bitumen : 1 Sand : 1 Limestone Dust (or Cement). 1* Pitch + Sand and Cement.	2 Pitch + Sand and Limestone Dust.	3† Hard Pitch + Sand and Cement.	4 Hard Pitch + Sand and Limestone Dust.	5§ Asphalt + Sand and Cement.	By Volume— 2 Bitumen : 1 Sand : 1 Limestone Dust (or Cement). 6 Asphalt + Sand and Limestone Dust.	7* Pitch + Sand and Cement.	8† Hard Pitch + Sand and Cement.	9§ Asphalt + Sand and Cement.	Remarks.
A Compression 24 hrs. at 0° C. per cent reduction of depth	....	....	....	....	....	....	5.8	0.67	1.48	Average of 2 tests
B Compression 24 hrs. at 5° C. per cent reduction of depth	21.5	28.7	6.0	3.6	14.1	13.9	....	6.6	5.8	Superimposed load = 0.38
C Compression 8 hrs. at 10° C. per cent reduction of depth	27.9	23.0	5.1	5.1	21.2	20.3	9.2	3.8	5.5	Lbs. per sq. in. on discs
D Compression ½ hr. at 20° C. per cent reduction of depth	48.8	40.6	13.0	10.1	23.0	24.3	14.8	7.5	8.8	3 ins. diam., ½ in. thick
E Compression hr. at 25° C. per cent reduction of depth	....	....	....	....	....	....	67.7	37.2	21.85	
F Penetration at 5° C. (in tenths of mm.)	11.0	11.0	5.0	3.5	17.0	16.0	9.0	3.5	10.0	No. 2 cambric needle, wtd. with 200 gms., acting 5 secs.
G Penetration at 10° C (in tenths of mm.)	22.0	23.0	8.5	8.0	24.0	23.0	18.5	7.0	14.0	
H Penetration at 20° C. (in tenths of mm.)	82.0	86.0	39.0	32.0	62.5	67.0	70.0	36 0	47.0	

I	Fracture—temperature for bar bent 180°, machine test ° C.	....	....	....	....	....	....	+2.5	+8.0	+3.0	Test bar, 12×1×¼ in. (two tests)
J	Fracture—Temperature for bar bent 180°, hand test °C.	−2.5	−2.5	+5.0	+2.5	−2.5	0.0	0.0	+7.5	0.0	(One test)
K	Healing at 10° C., kgs. force reqd. to pull cylinders apart‖	21.0	20.0	31.0	30.0	21.0	19.0	24.5	24.5	12.5	Average of 3 tests, in air, 1 hr.
L	Healing at 5° C., kgs. force reqd. to pull cylinders apart	....	....	....	....	....	....	34.0	22.0	13.0	Average of 3 tests, in air, 1 hr.
M	Healing at 10° C., kgs. force reqd. to pull cylinders apart	....	....	....	....	....	....	27.0	22.0	12.0	1 test, 2½ hrs.
N	Healing at 10° C., kgs. force reqd. to pull cylinders apart	....	....	....	....	....	....	24.5	23.5	14.0	1 test, 4 hrs.
O	Healing at 10° C., kgs. force reqd. to pull cylinders apart	....	....	....	....	....	....	14.0	0.5	0.0	1 test in water, 4 hrs.
P	Fracture by impact of 2 kgs. weight, at 32° F., cm. fall of weight	15	14.0	8.0	8.0	15.0	16.0	14.5	9.0	17.0	Average of 2 tests. Cylinders 1¾×1¾ ins.
Q	Effect of gas drip‡ on films .2 cm. thick, minutes to eat through film	....	....	....	....	....	....	163	200	9	Average of 2 tests
R	Ductility at 30° F., cm. elongation	0.0	0.0	0.0	0.0	0.0	2.0	1.0	1.0	0.0	Average of 2 tests. Specimens 1 sq. cm. cross-section
S	Ductility at 50° F., cm. elongation	15.0	35.0	8.0	8.0	13.0	11.0	33.0	2.0	5.0	
T	Ductility at 70° F., cm. elongation	21.0	31.0	18.0	9.0	15.0	19.0	14.0	29.0	11.0	

* Pitches Nos. 1, 2 and 7 are as specified on page 281.
† Hard pitches Nos. 3, 4 and 8 are a mixture of two pitches giving a penetration equal to that of Asphalts 5, 6 and 9.
‡ Gas drip used in an average mixture from 4 New York gas works, specific gravity at 15.5° C. =0.897.
§ Asphalts Nos. 5, 6 and 9 are as specified on page 282.
‖ All cylinders 1 inch diameter, 1½ inches high; superimposed weight, 175 grams.

(2) The coal-tar pitch curves show that the pitch is more affected by change of temperature than the asphalt. This is not quite obvious, however, unless we assume a common point for both curves, which would very likely be near the melting-point of both materials. Then, if measured from this point, the above fact is readily proved.

(3) Of both pitch and asphalt mastics the pitch mastic of proportions 2 : 2 : 1 is more affected by temperature changes.

(4) Of the asphalt mastics, the one of proportions 1 : 1 : 1 is least affected by temperature changes.

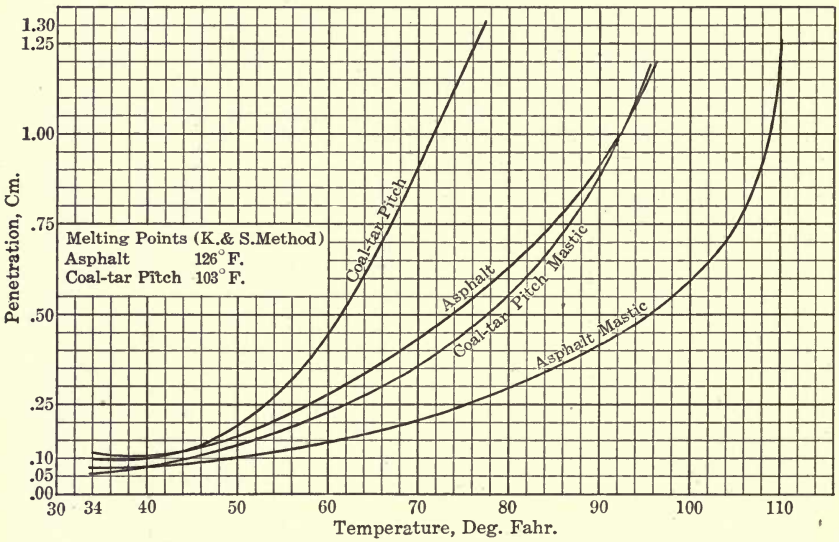


FIG. 108.—Relation of Penetration to Temperature of Asphalt and Coal-tar Pitch; also Asphalt and Coal-tar Pitch Mastic, Mixed in the Proportions of 1 Part Bitumen, 1 Part Sand, and 1 Part Limestone Dust. (Points of Curves are the Means of three Sets of Readings on Penetration Machine Using a No. 2 Cambric Needle, Weighted to 100 Grams and Acting for Five Seconds.)

The following conclusions are noted from a study of the ductility curves:

(*a*) Asphalt and its mastics are more ductile than coal-tar pitch (both of the same melting-point), but its rate of change of ductility is less, hence it is less affected by temperature changes.

(*b*) For work exposed to great temperature changes the asphalt is to be preferred to coal-tar pitch. For work not exposed to great temperature changes coal-tar pitch is to be preferred on account of its greater chemical stability.

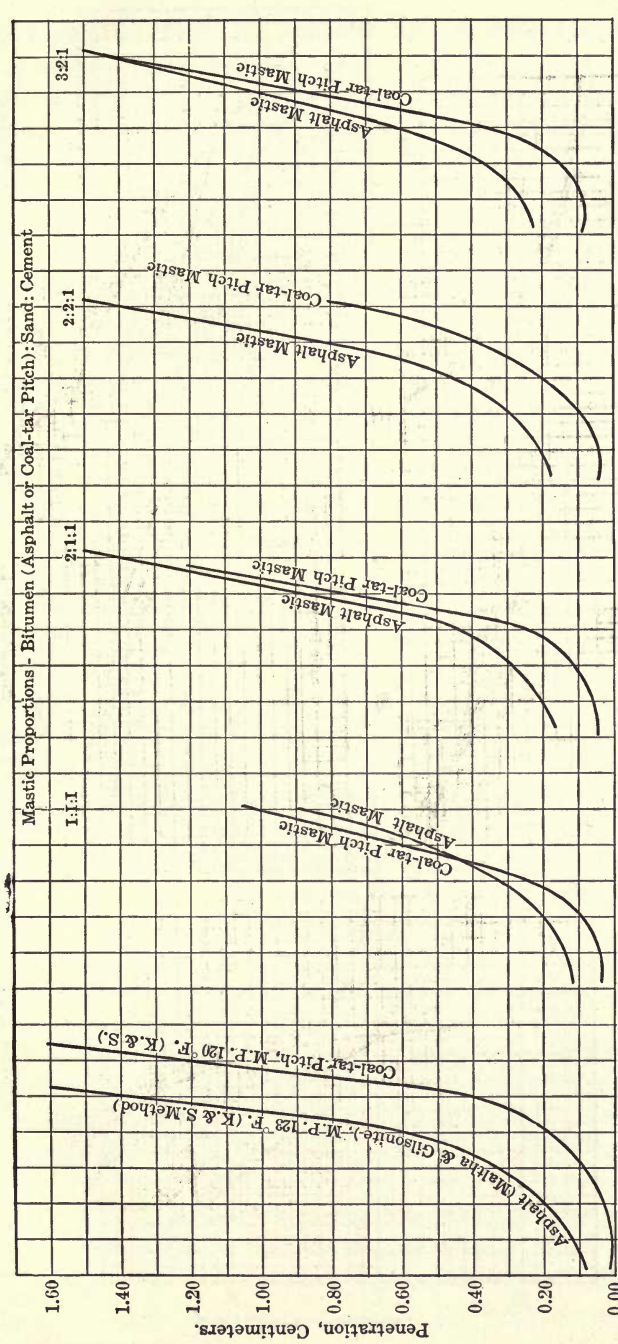


FIG. 109.—Relation between Penetration and Temperature of Asphalt and Coal-tar Pitch, also between Asphalt Mastic and Coal-tar Pitch Mastic Mixed in the Proportions Indicated.

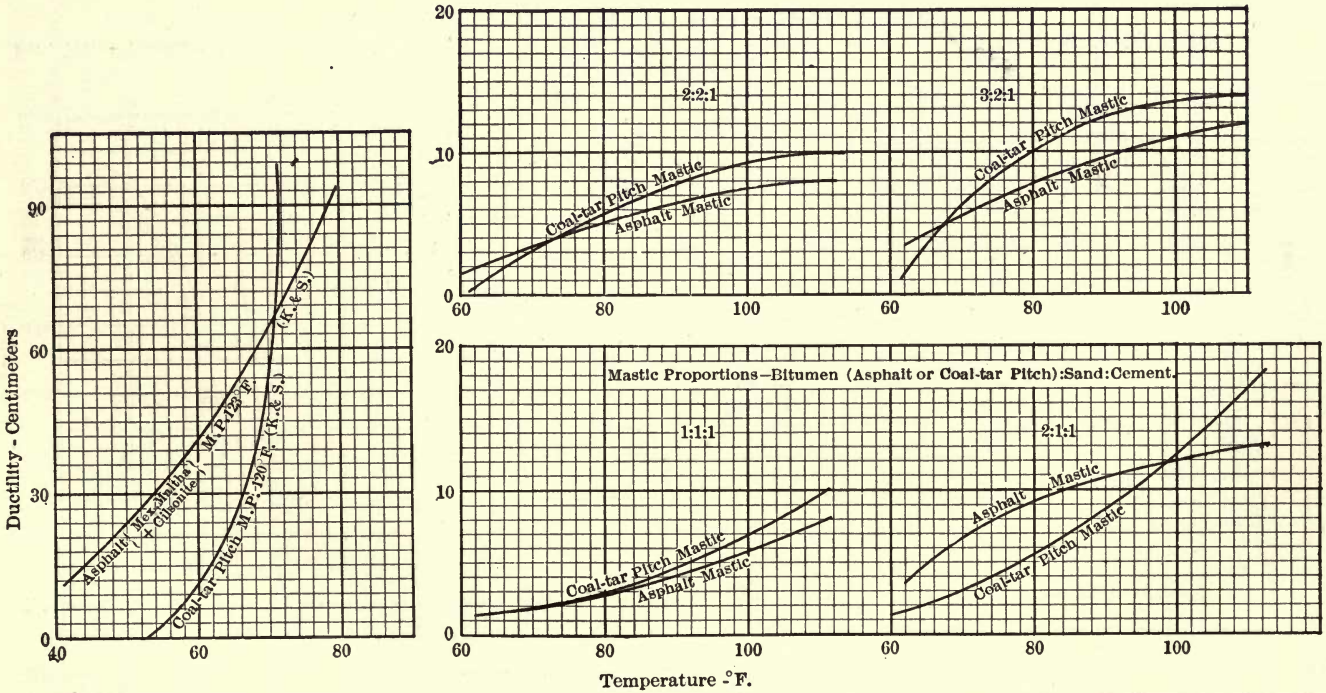


FIG. 110.—Relation between Ductility and Temperature of Asphalt and Coal-tar Pitch, also between Asphalt Mastics and Coal-tar Pitch Mastics, Mixed in the Proportions Indicated.

Comparative Tests on Coal-tar and Asphalt Mastics.* Heretofore asphalt alone has been used for making mastic for brick-in-mastic usually used for waterproofing underground structures. The purpose of these tests was to ascertain the adaptability of straight-run coal-tar pitch for making mastic for the same purpose.

The tests were made to cover the requisite properties of a mastic for waterproofing by this method, these properties being as follows:

(1) The mastic must have a small and limited compressibility at a temperature between 32 deg. Fahr. (0 deg. Cent.) and 77 deg. Fahr. (25 deg. Cent.)

(2) It must be flexible or pliable, that is, it must be able to bend on itself without fracture at 40 deg. Fahr. (4.5 deg. Cent.) or less.

(3) It must be adhesive and cohesive enough to heal at 40 deg. Fahr. or less.

(4) It must be tough enough at 32 deg. Fahr. to resist cracking due to impact and vibration caused by moving loads.

(5) It must be reasonably ductile at temperatures between 32 deg. Fahr. and 77 deg. Fahr.

(6) It must be of uniform consistency however proportioned.

(7) The extracted bitumen must have very little (not more than 3 per cent) volatile oil.

(8) The mineral aggregate must pass 100 per cent through a 10-mesh sieve.

Two kinds of coal-tar pitch and one of asphalt were used in making the test specimens. One pitch was a straight-run product meeting the specifications given on page 281; the other was also a straight-run product brought down to the same penetration as the asphalt under test. The asphalt was a refined Mexican oil made to meet the specifications given on page 282.

Two sets of tests were made. In one, the ingredients were proportioned by weight—one sand, one limestone dust or cement, four bitumen. In the other, the ingredients were proportioned by volume—one sand, one limestone dust or cement, two bitumen.

The reason for making two sets of tests, one with about twice as much bitumen as the other, was to ascertain the relative effect on the properties of the mastic by the presence of more or less bitumen.

Since in the past asphalt mastic has been used exclusively in the brick-in-mastic system of waterproofing, and since there is no reported failure of this method or material, it was accepted as the

*Test made under supervision of author in the Research Laboratory of the Barrett Company, in 1915.

standard, i.e., all results were compared to the results obtained on the asphalt mastic. These values, given in Table XVI, were averaged and the following conclusions are drawn from a study of this table:

(1) A limited amount of compressibility being both useful and necessary in a bituminous mastic, this property shows up generally in favor of the hard-pitch mastic.

(2) Penetration—a measure of the hardness of the mastic, but not a very reliable test, owing to the presence of sand particles—is generally in favor of the hard-pitch mastic.

(3) The bending test, showing the temperature at which fracture will occur, shows in favor of the soft-pitch mastic; this may be bent at about 140 deg. Fahr. (60 deg. Cent.) lower than the hard-pitch mastic.

(4) The healing test, probably the most important, indicating the inherent capacity of the mastic to restore itself after cracking, shows in favor of both pitch mastics.

(5) The impact test, indicating the resiliency of the mastics, a property important for the conditions under which the material is usually used, shows in favor of the soft-pitch mastic.

(6) The ductility test, indicating the tenacity of the material, shows in favor of the soft-pitch mastic.

(7) The gas-drip test, indicating the capacity of the material to resist the deteriorating effect of gas-polluted earth, shows in favor of both the pitch mastics. This resistance is mainly due to the presence of the free carbon in the pitches, but is obviously not a governing property.

From the foregoing it is evident that both pitches are better in some of the desirable properties than the asphalt, but neither excels in all the requisite properties. But by interpolating the results given in the table, a grade of coal-tar pitch was evolved, meeting the specifications for brick-in-mastic waterproofing given in Chapter VIII, and this may be used under the same conditions where the asphalt mastic is used.

Volume Reduction of Asphalt Mastics. In the mastic and waterproofing industries it is a matter of common knowledge that the volume of the finished mastic is not equal to the total volume of its ingredients, just as in the case of concrete. The loss in volume was assumed to be anywhere between 5 and 20 per cent. The following test was therefore made to determine this value with closer approximation:

Equal volumes of asphalt, sand and cement were mixed in a

fire-heated kettle until a satisfactory mastic was formed. The volume was then measured and found to be approximately 30 per cent less than the total volume of ingredients.

Another mastic was then made with equal volumes of asphalt and mineral aggregate; the latter composed of one part cement and three parts sand. This mixture showed about 20 per cent loss in volume. Other mixtures were made and showed losses between these limits depending on the proportions of sand and cement in the mineral aggregate, and the length of time the mastic was stirred. This established the fact that 20 per cent and not 5 per cent is the minimum, and about 30 per cent the maximum reduction of volume for mastic used with bricks to form what is known as the brick-in-mastic waterproofing envelope. But even these figures are materially affected by the duration of the mixing process, the volume further decreasing with prolonged stirring.

Mastic Bond Affected by Surface Condition of Bricks. In an effort to determine the relative bonding power of waterproofing mastic on bricks in various conditions, the following test was made:

Five bricks were embedded in a 50 per cent asphalt mastic, that is, a mastic composed of fifty parts asphalt and fifty parts mineral matter. The first brick embedded was dry and clean; this was followed by a moist brick, then by a wet brick, then by two bricks somewhat blackened with soot, as would be the case if the bricks were dry heated over an open wood fire, as is often done. When the mastic cooled and hardened the bricks were pulled up and showed the following:

(1) The dry and clean brick could not be extracted from the mastic intact.

(2) The moist brick showed but little bond and was easily extracted.

(3) The wet brick showed no bond at all.

(4) The soot-blackened bricks showed fairly good bond, enough to demonstrate that a thin coat of soot is not objectionable in brick-and-mastic work.

Relative Compression of Plain Brick, Brick and Mortar and Brick-in-mastic. The brick-in-mastic specimens were made in accordance with prevailing practice, that is, two bricks were laid in mastic, side by side, on their largest bed, as stretchers. But for testing, the specimens were not incased in concrete, as is usually done in practice. The specimens were four bricks high, with a minimum of $\frac{1}{8}$-inch joints and each completely covered with asphalt mastic. The proportions of the mastic ingredients were about 40 per cent asphalt,

30 per cent sand and 30 per cent cement, by weight. The bricks were the ordinary building variety, $2\frac{1}{4}$ by $3\frac{3}{4}$ by 8 inches.

The joints of the wooden form used for making the specimens were purposely made not absolutely tight, as this is a condition which occasionally occurs in practice. As a result, some of the hot mastic leaked out, leaving a considerable void between two bricks above the level of the leak.

One of the forms was also made somewhat narrow, that is, its width did not permit more than about a $\frac{1}{16}$-inch joint. The result was that on inserting the brick the mastic was squeezed out between the form-side and brick. The latter was in consequence only partly covered with mastic.

These conditions illustrate the necessity of making tight-joint forms and also wide enough to allow sufficient mastic between all brick faces.

Three specimens were made as above noted (in good forms) and when tested for compression at about 70 deg. Fahr. (21 deg. Cent.), gave the results noted in Table XVII, to which, also, are added for comparison, the ultimate compressive strength of plain brick and brick and mortar.

TABLE XVII.—ULTIMATE COMPRESSIVE STRENGTH OF BRICK AND MASTIC, BRICK AND MORTAR AND PLAIN BRICK

ULTIMATE COMPRESIVE STRENGTH

(Lb. per Square Inch)

Brick and Mastic.	Brick and Mortar.*	Plain Bricks.†
360	2520(*a*)	5120
281	2440(*a*)	5060
421	3776(*b*)	4880

*Compression on column, 8 × 8 inch base, 1 foot 4 inches high, of common brick and mortar, (*a*) Lime mortar, 1 : 3 proportion; (*b*) Portland cement mortar, 1 : 2 proportion.
† Compression on largest bed of single bricks.

On all three tests of the brick-in-mastic, the bricks failed first. The reason for this is that the mastic, when compressed, tends to spread and actually does so, and however slight this may be, it places the brick under a transverse tension, consequently reducing its compressive strength, as indicated in the table above. However, it should be borne in mind that the compressive strength of brick-in-mastic would be increased considerably, perhaps quadrupled, by being encased in concrete, as it actually is in practice. The temperature of the brick-in-mastic will also have a marked effect

upon its strength. A continued, comparatively low temperature, however, will not prevent the ultimate destruction of the bricks by transverse tension, but only retard it, unless, of course, the brick-in-mastic is well encased in masonry to prevent it.

Effect of Temperature of Saturants on Waterproofing Fabrics. The purpose of this test was to determine (1) the effect of high temperatures on waterproofing felt and fabrics while in course of treatment; (2) the charring temperature of these materials; (3) the result of treating fabrics without the use of the usual compression rollers.

Specimens of cotton drill and open-mesh jute burlap were cut into workable pieces and treated as follows: Eighteen pieces were saturated with asphalt at different temperatures ranging from 180 deg. Fahr. (82 deg. Cent.) to 500 deg. Fahr. (260 deg. Cent.), raised by increments of 30 deg. Fahr.; fourteen pieces were saturated with coal-tar pitch at different temperatures ranging from 180 deg. Fahr. to 420 deg. Fahr. (215.5 deg. Cent.) raised by increments of 25 deg. Fahr.; ten pieces were saturated with a mixture of asphalt and coal-tar pitch in equal proportions; the temperatures of the mixture ranged from 300 deg. Fahr. (149 deg. Cent.) to 520 deg. Fahr. (271 deg. Cent.), raised by increments of 50 deg. Fahr.

The melting point of the pitch used was about 120 deg. Fahr. (49 deg. Cent.) and that of the asphalt about 160 deg. Fahr. (71 deg. Cent.), both determined by the cube-in-water method.

The method of saturating the forty-two specimens was as follows: Each piece was drawn slowly, as in practice, through its saturant, completely immersed, and, when withdrawn, was hung up immediately to dry in the air. Of course, this is not the method used by manufacturers of waterproofing products for treating fabrics. At the factory the felts and fabrics are drawn through steam-heated compression rollers immediately after they leave the saturating tank, which operation forces the compound into the fibers and removes the excess saturating material. (See Fig. 60.)

It was interesting and instructive to know though what the resulting condition of the product is when treated as above. All were well saturated but excessively coated with bitumen. The burlap specimens showed very few or no open meshes remaining. Both the asphalt- and pitch-saturated specimens, when weighed, showed a gradual decrease in the amount of saturant with the increase of temperature, but the "A.-P." (asphalt-pitch) mixture saturated specimens showed almost constant weight of saturant notwithstanding increase of temperature; in other words, the "A.-P." mixture

remained at practically the same consistency while the others became more fluid. The pitch-saturated fabrics lost their tackiness first, then the "A.-P." saturated fabrics and lastly the asphalt-saturated fabrics. The " A.-P." mixture saturated specimens were devoid of ductility, cracked easily on being bent around the finger at normal temperature and showed a dull-black, rough and pitted surface. The asphalt-saturated and pitch-saturated samples showed a smooth and lustrous surface.

Several specimens of untreated felt, raw burlap and cotton drill were then put into a sand bath and heated gradually; at about 400 deg. Fahr. (204.4 deg. Cent.) the felt charred; at 425 deg. Fahr. (218.3 deg. Cent.) the burlap charred and at about 450 deg. Fahr. (232.1 deg. Cent.) the cotton drill began to char. The charring temperatures thus obtained verified previous values obtained during the saturation process.

Manifestly the fabrics must be drawn through compression rollers to obtain not only good saturation but also the proper amount of coating and, in the case of burlap, sufficient open mesh in the finished product. The temperature of the saturant has much to do with the degree of saturation and is, in fact, almost proportional to it. The possibility of charring the felts and fabrics during treatment is remote because such temperatures never exceed 350 deg. Fahr. in practice and besides, the bitumen, especially the pitch, would be injured first by over-heating, and detected by the excessive fumes it gives off at the higher (charring) temperatures. The saturant composed of equal parts of asphalt and coal-tar pitch is obviously not as good as either of the other two when used as a saturant for fabrics.

Relative Amount of Saturant and Coating Material on Treated Waterproofing Felts and Fabrics

It has often been stated that jute fabric cannot be saturated as well as felt. The results noted in Table XVIII indicate that this is true for asphalt-treated fabric but quite the reverse for pitch-treated fabric. It must, however, be borne in mind that the saturation of the jute fabric, even with asphalt, is only a preliminary step to its final treatment, while with the saturation of the felt its treatment is completed. This is true of most asphalt- and all pitch-treated felts. On the other hand, saturated cotton fabric (saturation being its only treatment) has 25 per cent more saturant than the felt.

TABLE XVIII.—RELATIVE AMOUNT OF SATURANT AND COATING ON TREATED WATERPROOFING FELTS AND FABRICS

No.	Material.	Weight in Grams Per Square Foot.					Treated Material (Based on Raw Materials).		
			Asphalt-Treated.		Pitch-Treated.				
		Untreated.	Saturated.	Saturated and Coated.	Saturated	Saturated and Coated.	Per Cent of Saturant.	Per Cent of Coating	Per Cent of Total Bitumen.
1	Open-mesh jute fabric	21.70	29.80	71.30	.....	.....	37.1	190.0	227
2	Open-mesh jute fabric	25.56	59.80	80.11	.....	.....	133.0	79.4	213
3	Open-mesh jute fabric	20.30	35.82	61.82	.....	.....	76.4	128.0	204
4	Open-mesh jute fabric	22.59	45.80	68.00	.....	.....	102.0	98.0	202
5	Open-mesh jute fabric	21.60	.....	50.35	.....	.....	.....	.....	133
6	Open-mesh jute fabric	24.55	33.65	61.45	.....	.....	37.0	113.0	150
7	Open-mesh jute fabric	21.60	.....	59.95	.....	.....	.....	.....	177
8	Open-mesh jute fabric	21.20	.....	47.50	.....	.....	.....	.....	124
9	Open-mesh jute fabric	19.95	37.60	70.05	.....	.....	88.0	162.0	251
10	Open-mesh jute fabric	21.15	36.55	75.35	.....	.....	72.7	183.0	256
11	Open-mesh jute fabric	22.00	.....	89.40	.....	.....	.....	.....	306
	Averages.....	20.18	39.70	61.20	.....	.....	78.0	136.2	203.9
12	Open-mesh jute fabric	21.70	.....	.....	47.05	56.00	116.0	41.2	157
13	Open-mesh jute fabric	19.10	.....	.....	59.90	75.75	214.0	82.9	295
14	Open-mesh jute fabric	20.35	.....	.....	52.10	87.25	155.0	172.0	328
15	Open-mesh jute fabric	19.55	.....	.....	51.90	68.75	165.0	86.1	251
16	Open-mesh jute fabric	18.45	.....	.....	62.30	71.60	237.0	50.2	287
17	Open-mesh jute fabric	21.05	.....	.....	58.90	81.45	179.0	107.0	286
18	Open-mesh jute fabric	22.50	.....	.....	64.20	82.70	185.0	81.8	266
19	Open-mesh jute fabric	20.30	.....	.....	49.65	78.70	143.0	142.0	286
	Averages.....	20.30	.....	.....	55.70	75.30	174.0	95.4	269.5
20	Felt (light grade) ..	28.75	.....	.....	62.85	.....	118.0	.....	.....
21	Felt (light grade) ..	25.25	.....	.....	65.00	.....	156.0	.....	.....
22	Felt (light grade) ..	22.25	.....	.....	47.50	.....	113.0	.....	.....
23	Felt (light grade) ..	28.89	.....	.....	66.17	.....	135.0	.....	.....
24	Felt (light grade) ..	27.40	.....	.....	52.90	.....	93.0	.....	.....
25	Felt (light grade) ..	20.55	.....	.....	35.62	.....	73.2	.....	.....
	Averages.....	25.50	.....	.....	55.30	.....	114.7	.....	.....
26	Felt (light grade) ..	29.90	79.25	.....	.....	.....	165.0	.....	.....
27	Felt (light grade) ..	17.30	34.70	.....	.....	.....	101.0	.....	.....
28	Felt (light grade) ..	26.20	56.80	.....	.....	.....	116.0	.....	.....
29	Felt (light grade) ..	25.60	53.05	.....	.....	.....	107.0	.....	.....
30	Felt (light grade) ..	21.60	44.70	.....	.....	.....	106.0	.....	.....
	Averages.....	24.10	53.70	.....	.....	.....	119.0	.....	.....
31	Felt (heavy grade)...	59.35	121.20	.....	.....	.....	104.0	.....	.....
32	Felt (heavy grade)...	58.51	182.14	.....	.....	.....	211.0	.....	.....
33	Felt (heavy grade)...	50.60	125.50	.....	.....	.....	146.0	.....	.....
34	Felt (heavy grade)...	64.20	157.60	.....	.....	.....	145.0	.....	.....
35	Felt (heavy grade)...	73.80	161.90	.....	.....	.....	119.0	.....	.....
36	Felt (heavy grade)...	91.70	157.10	.....	.....	.....	71.0	.....	.....
	Averages.....	66.40	150.90	.....	.....	.....	132.7	.....	.....
37	Cotton fabric.....	17.05	.....	43.05	.....	.....	152.0	.....	.....
38	Cotton fabric.....	19.30	.....	45.52	.....	.....	135.0	.....	.....
	Averages.....	18.20	.....	44.30	.....	.....	143.5	.....	.....

It has also been stated that an asphaltic-treating compound for jute fabric intended for membrane waterproofing with coal-tar pitch as a binder is injurious to the membrane because the two materials are forced to mix (on account of the binder being applied hot), and produce thereby an inelastic and perhaps deleterious compound. Careful investigation, however, seems to show that the amount of treating compound used in the fabric is so little in comparison with the amount of binder used in the membrane that there is no apparent harm in using asphalt-treated fabric with coal-tar pitch binder. The results of weights of specimens noted in Table XVIII permit the determination of the proportion of treating compound to binder used to form, say, a 3-ply or a 6-ply membrane; for instance, a square foot of a 3-ply fabric membrane, approximately $\frac{1}{4}$-inch thick, weighs 2 pounds, of which 80 per cent is pitch-binder and 15 per cent asphaltic-treating compound. Pitch and asphalt in these proportions, were they actually mixed, would not produce a very bad compound to be used as a binder. In the field, not more than the coating on the fabric mixes with the binder, therefore the percentage of treating compound that mixes with the binder is still less than that given here.

Further facts disclosed in Table XVIII are that though asphalt-treated jute fabric has only about 75 per cent as much total bitumen (that is, saturant plus coating material) as the pitch-treated fabric, the amount of coating proper on the asphalt-treated fabric is 45 per cent greater than that on the pitch-treated fabric.

Asphalt-treated and pitch-treated felts of approximately the same weights are equally well saturated, but heavy felts contain about 10 per cent more saturant than lighter felts.

Effect of Drinking Water on Waterproofing Fabrics. The purpose of this test is to determine the effect on treated and untreated fabric of one-half year's immersion in water and one-half year's gradual drying.

In March, 1914, nine specimens of jute fabric, some treated with asphalt and some with coal-tar pitch and one untreated specimen, were immersed in plain water, contained in a rectangular tank 1 by 1 by 3 feet. The specimens were suspended from strings stretched across the tank and labeled for identification. The water was constantly replenished for six months after which it was allowed to evaporate completely, which also took about six months.

In March, 1915, the specimens were carefully examined, and the following results noted. The untreated jute burlap though thor-

oughly wet for at least six months, had retained its strength completely but was a little stiff and darker in color than originally. The bituminous treated specimens showed hardly any loss of strength and practically no deterioration. Where the coating on the fabric was good originally, the fabric was entirely unaffected, that is, no water penetrated the fabric fibers. The bitumen retained its elasticity and the fine sawdust, which is sprinkled on the surface of the fabric to prevent self adhesion in the rolls during shipment and storage, remained intact. Where the fabric was poorly saturated, a slight loss of tensile strength was manifested. In general, however, the asphalt treated specimens showed somewhat less resistance than the specimens of fabric treated with coal-tar pitch.

The test proves (1) the value of thoroughly coating and saturating the fabric, because thereby it is prevented from absorbing water, and (2) that plain water is not particularly injurious to bituminous treated fabric.

Effect of Ground Water on Waterproofing Fabrics. To determine the effect on fabrics treated with asphalt and with coal-tar pitch by the action of ground water in direct contact with them, thirteen specimens of treated jute fabric, each about 4 by 6 inches, were buried about 3 feet in the ground at City Hall Park, N. Y., near the new Broadway Subway location, for a period of 106 days (from May 6th to August 22d, 1914). Table XIX shows the characteristics of the interred waterproofing fabric.

In another test similar to the above, various grades of cotton fabric, paper fabric and felt were buried in the ground at Battery Park, N. Y., at a depth of 4 feet. In less than three months, when the specimens were examined, it was found that the cotton and paper fabrics had almost completely decayed and the felt had become so brittle that it broke in handling.

Another test of a similar nature with various cotton, jute and felt specimens, but this time each heavily coated with pitch or asphalt, showed on examination, after $2\frac{1}{2}$ months' burial, that both the fabric and felt were well preserved though the coatings were considerably pitted.

In each of the above tests the specimens were obtained from various manufacturers.

These tests conclusively prove the necessity of thoroughly coating any felt or fabric used as reinforcement in a bituminous waterproofing membrane. Also that the binder and not the felt or fabric is the waterproofing material in such a membrane.

TABLE XIX.—EFFECT OF GROUND WATER ON WATERPROOFING FABRICS

Before Burying.	After Burying.
(1). 7 oz. open-mesh asphalt-treated fabric; well saturated and coated.	Shows almost complete decay. Both asphalt and burlap are very brittle. No "life" left.
2. 7 oz. open-mesh asphalt-treated fabric; well saturated, one side well coated, other side poorly coated.	Shows no strength. Asphalt coating very brittle. Burlap saturated with water.
(3). 7 oz. open-mesh asphalt-treated fabric; well saturated and coated.	Shows brittleness and more or less decay. Lacks strength.
(4). 7 oz. open-mesh asphalt-treated fabric; poorly coated; not saturated.	Shows almost complete decay. Very brittle.
(5) 8 oz. open-mesh oil-tar pitch-treated fabric; poorly saturated but well coated; pliable.	Shows almost complete decay. Remainder is pliable but weak.
(6). 8 oz. open-mesh oil-tar pitch-treated fabric; well saturated and coated; somewhat stiff and brittle coating.	Is brittle, weak and decayed in several spots.
(7). Seven pieces of 7 oz. open-mesh asphalt- and pitch-treated fabric, more or less well saturated and coated.	Specimens so badly deteriorated that identification is impossible.

Relative Absorption and Strength of Raw and Treated Waterproofing Felts and Fabrics. To determine the relative amount of water absorbed by various waterproofing felts and fabrics, and also their relative tensile strength and stretch, 88 specimens, of which 35 were untreated, and the remainder treated with either asphalt or pitch, were partly immersed in water for three hours and weighed before immersion and at the end of the first and third hours. Then the specimens were allowed to dry, after which they were cut into 1-inch strips and tested for strength and stretch on a stretching machine. A review of Table XX reveals the following facts:

1. Untreated jute burlap is much more absorbent than paper fabric, cotton fabric, felt, building paper, and ready-roofing, all untreated.

TABLE XX.—RELATIVE ABSORPTION AND STRENGTH OF VARIOUSLY TREATED WATER-PROOFING MATERIALS

Material.	Treatment.			Per Cent Absorbed Compared to Weight of Original Specimen.		Tensile Strength, Pounds per Linear Inch.		Per Cent Strength.		Notes.
	Untreated.	Asphalt.	Tar or Pitch.	1 hour.	3 hours	Warp	Woof	Warp	Woof	
1 Jute burlap	Untreated.	.....	.....	68.4	82.7	46	50	6	6	Average of 7 specimens
	.....	Saturated only	.....	4.1	6.7	68	50	4½	10½	Average of 2 specimens
	.....	Saturated and coated	.....	2.4	3.4	85	63	5	8	Average of 13 specimens
	.....	.....	Saturated only with oil-tar pitch	6.4	6.4	127	82	6	6	1 specimen
	.....	.....	Saturated with creosote oil	13.2	20.7	122	92	3	4½	1 specimen
	.....	.....	Saturated and coated with oil-tar pitch	4.8	5.8	107	76	1	5	Average of 3 specimens
2 Paper fabric	Untreated.	.....	.....	22.2	30.8	40	35	10½	15	Average of 9 specimens
	.....	Coated only	.....	3.1	4.0	43	34	5	5	Average of 6 specimens
	.....	.....	Oil-tar pitch-coated only	4.4	4.4	38	36	6	7½	1 specimen
3 Cotton fabric	Untreated.	.....	.....	24.0	27.0	65	20	7½	60	Average of 3 specimens
	.....	Saturated only	.....	13.9	15.4	78*		21*		Average of 2 specimens
4 Felt	Untreated.	.....	.....	56.8	71.3	11		3		Average of 6 specimens
	.....	Saturated	.....	1.6	1.8	48		3		Average of 6 specimens
	.....	.....	Tar saturated	3.1	3.7	83		3		Average of 6 specimens
5 Building paper	.....	Coated	.....	3.2	3.8	40		1½		Average of 3 specimens
6 Ready (felt) Roofing	.....	Saturated and coated	.....	1.1	1.3	41		7½		Average of 2 specimens
7 Reinforced felt†	.....	Tar saturated	.....	5.8	5.8	111		15		1 specimen
8 Asbestos felt	Untreated	.....	.....	64.2	81.0	8		24		Average of 4 specimens
9 Blotting paper	Untreated	.....	.....	168.0	176.0	30		3		Average of 2 specimens
10 Newspaper	Untreated	.....	.....	37.8	44.4	14	9	1½		Average of 2 specimens

* It was impossible to ascertain definitely whether items in center of column represent warp or woof of specimens.

† Felt and cotton fabric combined; one ply of each.

TABLE XXI.—FORMS OF WATERPROOFING USED ON NEW YORK SUBWAYS*

	Above Ground Water Level†		Below Ground Water Level.†	
	Earth.	Rock.	Earth.	Rock.
Roof at stations	1-ply membrane, 1 or more layers of brick and mastic, 4-inch concrete‡	1-ply membrane, 1 or more layers of brick and mastic, 4-inch concrete	1-ply membrane, 2 layers of brick and mastic, 4 inch concrete	1-ply membrane, 2 layers of brick and mastic, 4-inch concrete
between stations	3-ply membrane, 4-inch concrete	3-ply membrane, 4-inch concrete	1-ply membrane, 2 layers of brick and mastic, 4-inch concrete	1-ply membrane, 2 layers of brick and mastic, 4-inch concrete
Side walls at stations	3-ply membrane, 4-inch concrete	3-ply membrane, 3-inch concrete‡	1-ply membrane, 8-inch brick and mastic, 4-inch concrete	6-ply membrane, 3-inch concrete
between stations	6-inch concrete with $\frac{5}{8}$-inch square rods, horizontal, 1 ft.–6 in. centers	3-inch concrete	1-ply membrane, 8-inch brick and mastic, 4-inch concrete	6-ply membrane, 3-inch concrete
Floor at and between stations	12-inch concrete	4-inch concrete	4-inch concrete, 1-ply membrane, 5-in. brick and mastic, 6-in. concrete	4-inch concrete and drain pipes

* A minimum of 2 inches of concrete outside all steel surfaces is included in the thickness of walls and roof where waterproofing is applied.

† Ground water level is assumed to be 2 feet above M. H. W., or based on exact data where available.

‡ The 3-inch and 4-inch concrete is used as outside protection for the waterproofing.

2. Saturated (only) jute burlap is but little more absorbent than saturated paper fabric and felt, but much less absorbent than saturated cotton fabric.

3. Untreated jute burlap will absorb in one hour about 70 per cent, and in three hours about 80 per cent of its weight of water, while the same burlap, asphalt-saturated and coated, will absorb in one hour only about $2\frac{1}{2}$ per cent and in three hours only about $3\frac{1}{2}$ per cent of its weight of water; while the oil-tar saturated and coated burlap will absorb in one hour about 5 per cent and in three hours about 6 per cent of its weight of water.

4. Untreated paper fabric will absorb in one hour about 20 per cent and in three hours about 30 per cent of its weight of water, while the same paper fabric, coated either with asphalt or pitch, will absorb about 4 per cent of its weight of water during both periods.

5. Untreated cotton fabric will absorb in one hour about 24 per cent and in three hours about 27 per cent of its weight of water, while the same cotton fabric, treated, will absorb in one hour only 14 per cent and in three hours only 15 per cent of its weight of water.

6. Untreated felt will absorb in one hour about 55 per cent and in three hours about 70 per cent of its weight of water, while the same felt, asphalt-treated, will absorb about 2 per cent and the tar-treated felt about $3\frac{1}{2}$ per cent of its weight of water during both periods.

7. The tensile strength (of the warp) of asphalt-treated jute burlap is increased about 100 per cent and the tar-treated jute burlap over 125 per cent, as compared to the untreated burlap. The percentage of stretch is diminished by treatment and is less for the tar-treated than for the asphalt-treated fabric.

8. The tensile strength of treated paper fabric is practically the same as that of the untreated, but the stretch is only about 50 per cent as great.

9. The tensile strength of treated cotton fabric is about 20 per cent more than the untreated, but the stretch is about 200 per cent greater.

10. The tensile strength of asphalt-treated felt is increased about 300 per cent, and the tar-treated felt about 600 per cent. But the stretch is the same for both treated and untreated, this being an average of 3 per cent in a 2-inch length.

The above conclusions are based on consideration only of the warp of the fabrics.

It is interesting to note that ordinary blotting paper is about 200

per cent stronger than untreated felt of the same weight, but is about 200 per cent more absorbent, though their unit stretch is the same.

Immutability Test on Various Waterproofing Felts and Fabrics. To determine the effect of exposure to the elements for a period of time, thirty-four specimens of waterproofing felts and fabrics, variously treated, were left in the open air completely unprotected for periods ranging from five to ten months. During the time of their exposure they were subjected to rain, hail, snow and sunshine. From careful examination of these specimens, the following facts are made evident and considered as warranting attention: (1) The asphalt-treated fabric is practically unaffected by exposure. (2) Oil-tar pitch-treated fabric is not in itself affected, but tends to become stiff from the evaporation of the saturant oils. (3) Raw and pitch-treated felts are practically unaffected except for the latter, which tend to harden and become brittle, due to the evaporation of the saturant oils.

Hence the general conclusion: Pitch-treated felts or fabrics should not be stored in the open for more than a few weeks before using, and all membrane roofings should receive a top-coating of bitumen to preserve the top sheeting.

Compressibility of Treated Jute-fabric Waterproofing Membranes. The purpose of this test was to ascertain the amount of compression that a waterproofing membrane can withstand without rupture.

Six membranes were tested, two composed of three plies each, placed between ½-inch mortar discs; two composed of six plies each, also placed between ½-inch mortar discs, and one composed of six plies and one of twelve plies, both without bituminous binder or mortar protection discs.

The asphalt binder used in making half the specimens had a melting-point of about 125 deg. Fahr. (52 deg. Cent.) by the K. and S. method, and the pitch binder used for making the remaining specimens had a melting-point of about 120 deg. Fahr. (49 deg. Cent.) by the Cube-in-water method. The temperature of the specimens was about 75 deg. Fahr. (25 deg. Cent.) when tested.

When pressure was applied to each of the first four membranes, the mortar discs were the first to fail at about 1000 pounds per square inch, the membranes remaining uninjured. At about 2000 pounds per square inch the fabric began to push out on all sides. When pressure was released and the membrane examined it was found that when the membrane began to push out radially it was crushed to destruction at the center. The two membranes that were tested

without the binder and mortar discs were not affected at all at a pressure of about 3000 pounds per square inch. Both these membranes were merely compressed and became as hard as a board. On tearing the separate plies apart each of them was found to be uninjured except for the bituminous coating with which the fabric was treated, which had been forced into the open mesh of the fabric.

This test demonstrates that a built-up, jute fabric membrane can safely withstand a direct compression of 1000 pounds per square inch; that both pitch and asphalt binder of the melting-points and at the temperature indicated above behave alike for membrane waterproofing when subjected to compression.

CHAPTER VIII

WATERPROOFING SPECIFICATIONS

Specification Requisites. Many architects and engineers are not sufficiently familiar with waterproofing engineering, hence, in writing specifications, abstractions are freely made from one specification and used in another. Such practice is inadvisable and should be guarded against. In writing specifications there is usually required some of the lawyer's skill in phraseology and the experienced engineer's knowledge. For those not so fortunate as to possess both these qualities, a few remarks on the writing of waterproofing specifications will not be amiss.

The specification writer should avoid being general, for, to be specific is the first requisite of good specification writing. Waterproofing specifications, as indeed all specifications, should be written open enough to admit of fair competition. They should describe the materials, their properties and application well enough to enable manufacturers to make them, contractors to apply them, and engineers or inspectors to approve or reject the materials or their application, or the field work in general, on the strength of such specifications. They should be suited to the conditions surrounding the particular work. Sufficient instructions should be embodied in the specifications to enable the engineer to assure himself that the waterproofing work can be properly executed under them. Equivocal or incomplete statements should be avoided, while explanatory clauses should be inserted wherever necessary. The application of waterproofing materials is more difficult and important than their manufacture; hence, efficient and sufficient supervision should be called for. Specific laboratory tests should also be called for, and these should be basic, not supplemental as they often are at present. No waterproofing specifications should allow a variation from any numerical requirement for strength or composition, as determined by test, of anything more than is consistent with best practice for the particular property under consideration. Such values are given for a great many materials, and will be found in the book of yearly proceedings of the American Society for Testing Materials. But

while the results of some acceptance tests may vary more than others the governing values and their significance should be well understood before rejecting the material on such grounds. Easy identification and proper care of all waterproofing materials in the field should be provided for; also, access to the manufactories to observe the materials in the various stages of their manufacture. The intent of the specifications should be carefully set forth; the price agreed upon—a lump sum or per unit of completed work. The material alternatives, the guarantee and necessary bonds should be clearly set forth.

These few suggestions well pondered, and a careful study of all the conditions under which the work of waterproofing is to proceed, coupled with a knowledge of the properties of waterproofing materials—all in the hands of an experienced engineer or architect—would result in a type of specification under which litigation would be almost impossible.

The specifications considered herein are fairly representative of the advancement that the art of waterproofing has made and which it enjoys to-day. The selection is varied enough to be of assistance to the architect or engineer in drawing up waterproofing specifications for many kinds of structures. The specific information in each, though not always complete, is modern and in accord with present practice. Several specifications of proprietary waterproofing materials are included for their suggestive value. The same is true of the roofing specifications. Some specifications are given in full while only abstracts from others are stated to avoid cumbrance. A few original specifications and several specifications of the more common materials used in waterproofing engineering are included.

By a careful perusal and comparison of these specifications, it is believed the architect or engineer will find material guidance in drawing up explicit and practical waterproofing specifications.

Specifications for Waterproofing Materials

Treated Woven Cotton Fabric for Membrane Waterproofing. Woven cotton fabric for waterproofing purposes shall be made of a good grade of cotton. In its raw or untreated state, it shall contain no oils of any kind. It shall weigh not less than 5 ounces to the square yard and its thread count shall not be less than 50 by 60 per square inch. To be made into a waterproofing fabric, it shall be thoroughly saturated with either asphalt or coal-tar pitch meeting the requirements hereinafter specified. No oils or bitumen solvents shall be used to liquefy either the asphalt or pitch in order to produce

a thoroughly saturated fabric. The fabric after treatment shall weigh not less than three and one-half times the weight of the untreated fabric. During treatment, the temperature of the saturating material shall not exceed 275 deg. Fahr. (135 deg. Cent.). The fabric after treatment shall be elastic and have a stretch in either direction of at least five (5) per cent without fracture. A 1-inch strip, cut with the warp, shall sustain a weight of at least 60 pounds, and at least 50 pounds with the woof. It must be flexible at all temperatures between 32 deg. Fahr. and 150 deg. Fahr. (0 to 66 deg. Cent.), and shall not flake or crack when folded upon itself. It must be of such a nature as to readily conform to any unevenness of the surface to which it is applied.

The asphalt for treating the woven cotton fabric shall be a refined product meeting the following requirements: Its melting-point by the Kraemer and Sarnow method shall be 155 deg. Fahr. (68 deg. Cent.); its penetration by the Dow method shall be .30 cm., and its ductility not less than 10 cm. nor more than 20 cm. as measured on a Smith ductility machine.

The tar pitch for treating the woven cotton fabric shall be a straight-run, coal-tar pitch meeting the following requirements: Its melting-point by the cube-in-water method, shall be 110 deg. Fahr. (43 deg. Cent.); its penetration by the Dow method, shall be 1.5 cm.; the loss on heating in an electric oven, for five hours at 325 deg. Fahr. (163 deg. Cent.) shall be not more than 8 per cent and its free carbon content shall not be more than 28 per cent nor less than 22 per cent.

Specifications for Bituminous-treated Waterproofing Felt. The felt must be saturated with an approved asphalt or coal-tar pitch, and must conform to the following requirements:

The weight per 100 square feet shall be from 12 to 15 pounds saturated and 5 to 6 pounds unsaturated.

The saturation shall be thorough and complete.

The ash from the unsaturated felt shall not be less than 25 per cent by weight.

The wool in the unsaturated felt shall not be less than 10 per cent by weight.

Soapstone, fine sand, or other substance on the surface of the felt to prevent adhesion shall not exceed $\frac{1}{2}$ pound per 100 square feet of felt.

The asphaltic saturating compound and the coal-tar pitch saturant shall remain plastic, at ordinary temperatures, after being heated to 325 deg. Fahr. (163 deg. Cent.) for ten hours.

Both the asphalt- and tar-pitch-treated felts shall be soft, pliable and tough when received from the factory and until placed in the work.

The quotient obtained by dividing the tensile strength in pounds, of a strip 1 inch wide cut lengthwise, by the weight in pounds of 100 square feet shall not be less than 7, and, when cut crosswise, shall not be less than $3\frac{1}{2}$.

The strength saturated shall be at least 25 per cent more than the strength unsaturated, taken lengthwise (along the warp) and at least 15 per cent more taken crosswise (along the woof).

Remarks. The above specification applies mainly to a light-grade felt, such as is commonly used for roofing. A wool-content of 25 per cent produces the best felt, but unfortunately this has been reduced to practically zero in the ordinary felts used at the present time. The requirements for weight and strength called for is readily exceeded by an average good felt. Only the former, though, is important, since it is an index of the amount of preserving material in the felt.

Specifications for Bituminous-treated Jute Fabric for Waterproofing. Jute fabric for waterproofing purposes shall be made of jute burlap, saturated and coated with bitumen, and if necessary sprinkled with sawdust to prevent adhesion in the roll.

The burlap shall have a trade weight rating of either seven and one-half ($7\frac{1}{2}$) ounces or eight (8) ounces per square yard and shall show a uniform open mesh with a uniform thickness of thread in both the warp and the woof.

The bitumen used for saturating and coating the burlap shall be asphalt or coal-tar or oil-tar pitch meeting the following requirements:

The coal-tar pitch shall be either a straight-run pitch containing not less than 25 per cent, and not more than 32 per cent of free carbon; or an oil-tar pitch containing not less than 10 per cent of free carbon. The coal-tar or oil-tar pitch used as saturant shall melt at approximately 70 deg. Fahr. (21 deg. Cent.). The coal-tar or oil-tar pitch used as coating shall melt at approximately 175 deg. Fahr. (80 deg. Cent.). The melting-points are to be determined by the cube-in-water method.

The asphalt shall contain in its refined state not less than $98\frac{1}{2}$ per cent of bitumen soluble in cold carbon tetrachloride. The remaining ingredients shall be such as not to exert an injurious effect on the burlap.

The asphalt, both saturant and coating shall not flash below

350 deg. Fahr. (177 deg. Cent.) when tested in the New York State Closed Oil Tester. When heated in an electric oven for five hours at a temperature of 325 deg. Fahr. (163 deg. Cent.) it shall not lose over two (2) per cent by weight, nor shall the penetration at 77 deg. Fahr. (25 deg. Cent.) after such heating be less than one-half of the original penetration.

The melting-point of asphalt saturant shall be between 100 and 115 deg. Fahr. (38 and 46 deg. Cent.) and of asphalt coating, approximately 225 deg. Fahr. (107 deg. Cent.) as determined by the Kraemer and Sarnow method.

The consistency of the asphalt shall be determined by the penetration, which must be between 0.75 and 1.00 cm. for the saturant, and between 0.15 and 0.25 cm. for the coating.

A briquette of the saturant of a cross-section of 1 sq. cm. shall have a ductility of not less than fifty (50) centimeters and of the coating not less than five (5) cm. at 77 deg. Fahr. on a Smith ductility machine.

All tests herein specified must be conducted according to methods approved by the engineer.

The very fine sawdust shall be a granulated cedar, pine, or other suitable wood, and applied on one side of the fabric so that not more than 5 ounces will cover 100 square feet.

The burlap shall be thoroughly dried before being saturated; it shall be thoroughly saturated and coated with bitumen, but shall retain between 30 and 40 per cent of the open mesh of the untreated burlap. The fabric after treatment shall be pliable without flaking at all working temperatures after treatment.

The temperature of the saturant and coating materials during the process of treating the fabric shall not exceed 300 deg. Fahr. (149 deg. Cent.).

The machinery and method of saturating and coating the burlap shall be subject to the approval of the engineer.

The treated fabric shall have a tensile strength in the direction of its length (warp) of not less than eighty (80) pounds and in the direction of its width (woof), not less than sixty (60) pounds per lineal inch of test specimen.

The fabric, when examined under a magnifying glass, shall show the inner strands to be actually saturated and the outer strands well coated. A piece of fabric ripped along a line diagonal to the warp and the woof shall show thorough saturation of the strands. The percentage of open mesh may be approximated by holding a large piece of fabric before a light.

The finished fabric shall weigh not less than two and one-half ($2\frac{1}{2}$) times nor more than three and one-half ($3\frac{1}{2}$) times the weight of the raw burlap.

The finished roll of fabric shall unroll easily. The completed fabric shall be wound on a core or spool of wood, fiber or other strong material, not less than two (2) inches in its smallest dimension, and equal in length to the width of the fabric.

The fabric shall be delivered in rolls not exceeding one hundred seventy-five (175) feet in length. The width shall not be less than three (3) feet. The shrinkage due to saturation shall not exceed two (2) per cent. When the fabric is brought on the work it shall be stored in a dry and cool place, piled no more than four rolls high, never stood on ends, and protected against rain and other weather conditions as well as from injury from resting or falling weights.

Remarks. The above specifications are probably the most complete of their type. Fabric made according to them has been used very extensively and very successfully on the New York Subway System. Engineers sometimes contend that it is unnecessary to saturate and coat burlap, arguing that the bituminous binder applied on the work is sufficient to protect it. Experience has proven that saturation and coating of the fabric is essential for best results. The practice of applying untreated burlap, never very extensive, is gradually being abandoned.

Specifications for Asphalt for Waterproofing or Dampproofing.* These specifications cover asphalt for waterproofing and dampproofing recommended for use under uniformly moderate temperature conditions.

The melting-point shall be between 100 and 140 deg. Fahr. (38 and 60 deg. Cent.) as determined by the ball-and-ring method, and shall be specified for one of the following classes: 130 to 140 deg. Fahr. (54.5 to 60 deg. Cent.); 115 to 130 deg. Fahr. (46 to 54.5 deg. Cent.); 100 to 115 deg. Fahr. (38 to 46 deg. Cent.).

The penetration at 77 deg. Fahr. (25 deg. Cent.), under a load of 100 grams for 5 seconds, shall be not less than 50 nor more than 125.

The penetration shall bear the following relation to the melting-point: Penetration of 50 to 75 for melting-points between 130 and 140 deg. Fahr. Penetration of 75 to 100 for melting-points between 115 and 130 deg. Fahr. Penetration of 100 to 125 for melting-points between 100 and 115 deg. Fahr.

* Proposed tentative specifications, Proceedings American Society for Testing Materials, Vol. 17, pp. 712–722 (1917).

The ductility at 77 deg. Fahr. (25 deg. Cent.), when a briquette of the material having a minimum cross-section of 1 sq. cm. is pulled apart at the rate of 5 cm. per minute, shall not be less than 30 cm.

The specific gravity shall not be more than 1.08 at 77/77 deg. Fahr. (25/25 deg. Cent.).

The bitumen soluble in cold carbon bisulphide shall not be less than 95 per cent.

The loss of a 50-gram sample on heating at 325 deg. Fahr. (163 deg. Cent.), for five hours, shall not exceed 1 per cent. The penetration of the residue from this test shall not be less than 50 per cent of the original penetration.

The ash shall not exceed 4 per cent.

Specifications for Primer for Use with Asphalt for Waterproofing or Dampproofing.* These specifications cover primer for use when specified with asphalt for waterproofing or dampproofing.

The primer shall consist of an asphaltic base, complying in every respect with the specifications of asphalt for waterproofing below grade (page 267), which shall be thinned to ordinary paint consistency with a petroleum distillate having an end point on distillation not above 500 deg. Fahr. (260 deg. Cent.). Not more than 20 per cent of this petroleum distillate shall distill under 248 deg. Fahr. (120 deg. Cent.).

Specifications for Asphalt for Waterproofing Surface and Subsurface Structures.† Asphalt shall be used which is of the best grade, free from coal tar or any of its products, and which will not volatilize more than ½ of 1 per cent under a temperature of 325 deg. Fahr. (163 deg. Cent.) for seven hours.

It must not be affected by a 20 per cent solution of ammonia, a 25 per cent solution of sulphuric acid, a 35 per cent solution of muriatic acid, nor by a saturated solution of sodium chloride. It should show no hydrolytic decomposition when subjected, for a period of ten hours, to hourly immersions in water with alternate rapid dryings by warm air currents.

For metallic structures, exposed to the direct rays of the sun, the asphalt must not flow under 200 deg. Fahr. (93.5 deg. Cent.), nor become brittle at 0 deg. Fahr. (−17.7 deg. Cent.) when spread on thin glass.

For structures under ground, such as masonry arches, abutments, retaining walls, foundation walls of buildings, subways, etc., a flow

* Proposed tentative specifications, Proceedings American Society for Testing Materials, Vol. 17, Part 1, pp. 712–722 (1917).

† Chicago & Northwestern Railway Company.

point of 180 deg. Fahr. (82 deg. Cent.) and a brittle point of 0 deg. Fahr. will be required.

A mastic made from either grade of asphalt by mixing it with sand in the proportion of 1 of asphalt to 4 of sand, must not perceptibly indent, when at a temperature of 130 deg. Fahr. (54.5 deg. Cent.) under a load of 20 pounds per square inch. It must also remain pliable at a temperature of 0 deg. Fahr.

Remarks. It may be noted that the above specifications call mainly for physical tests. The kind of asphalt specified must necessarily be fluxed, as neither natural nor artificial asphalts can, of themselves, meet the above requirements. Yet the few tests called for are undoubtedly sufficient to guarantee the quality of the asphalt, for the loss on heating test limits the amount and grade of fluxing material, and the flow point and brittle point requirement limits the grade and quality of the original asphalt. Unless both of these materials are of the proper consistenty and properly blended, the results of the tests would not check with the requirements. The test requirements of the above specifications are a material departure from the almost standard requirements for waterproofing asphalts, which usually call for a melting-point test, loss on heating, solubility in carbon bisulphide or carbon tetrachloride, solubility in petrolic ether, penetration, ductility, and specific gravity.

In the flow-point test requirement, a time limit should be specifically stated, as also in the indent test for mastic, because neither the asphalt nor the mastic will fulfill the requirements in unlimited time. It would seem, though, that one of the so-called melting-point tests would be better to use then the flow-point test because the function of the latter is primarily to show the relative flowing properties of bituminous, and besides, it is not extensively used in the industry.

Specifications for Coal-tar Pitch for Waterproofing and Dampproofing.* These specifications cover coal-tar pitch for waterproofing and dampproofing recommended for use under uniformly moderate temperature conditions.

The melting-point as determined by the cube-in-water method, shall be between 120 and 140 deg. Fahr. (49 and 60 deg. Cent.). In specifying the melting-point desired within the above limits, a variation of not more than 5 deg. Fahr. (2.5 deg. Cent.) in either direction will be permitted.

The penetration at 77 deg. Fahr. (25 deg. Cent.), under a load of

* Proposed tentative specifications, Proceedings American Society for Testing Materials, Vol. 17, Part 1, pp. 712–722 (1917).

100 grams for five seconds shall not be less than 20 nor more than 120.

The ductility, at 77 deg. Fahr. when a briquette of the material having a minimum section of 1 sq. cm. is pulled apart at the rate of 5 cm. per minute shall not be less than 40 cm.

The loss of a 20-gram sample on heating at 325 deg. Fahr. (163 deg. Cent.) for five hours on pitch of melting-point between 120 and 130 deg. Fahr. (49 and 54.5 deg. Cent.) shall not exceed 9 per cent, and on pitch of melting-point between 130 and 140 deg. Fahr. (54.5 and 60 deg. Cent.) shall not exceed 7 per cent.

The specific gravity of the pitch at 77/77 deg. Fahr. (25/25 deg. Cent.) shall not exceed the limits of 1.24 and 1.34.

The specific gravity at 140/140 deg. Fahr. (60/60 deg.Cent.) of the distillate to 671 deg. Fahr. (355 deg. Cent.) shall not be less than 1.06.

The matter soluble in hot toluol-benzol shall not be less than 65 nor more than 85 per cent.

The ash shall not exceed 1 per cent.

Specifications for Creosote Oil for Priming Coat with Coal-tar Pitch for Waterproofing and Dampproofing.* When it is specified that previous to the mopping on of the hot coal-tar pitch, the wall, floor, or foundation, shall be painted with a priming coat, the following specifications for creosote oil shall apply:

Creosote oil shall be of pure tar distillate, free from any substance foreign to a tar distillate.

The oil shall be entirely fluid at 100 deg. Fahr. (38 deg. Cent.).

The specific gravity at 100 deg. Fahr. shall not be less than 1.00 nor more than 1.06.

Insoluble matter in hot benzol shall be less than 1 per cent.

When distilled, it shall yield: (*a*) water not more than 2 per cent; (*b*) not more than 5 per cent shall distill under 392 deg. Fahr. (200 deg. Cent.); (*c*) not more than 50 nor less than 30 per cent shall distill under 455 deg. Fahr. (235 deg. Cent.): (*d*) the residue above 671 deg. Fahr. (355 deg. Cent.) shall not exceed 15 per cent; (*e*) the residue shall be soft; (*f*) the specific gravity at 100 deg. Fahr. (38 deg. Cent.) of the fraction distilling between 455 and 599 deg. Fahr. (235 and 315 deg. Cent.), shall not be less than 1.00.

Coal-tar Pitch for Mastic Waterproofing. Coal-tar pitch intended for mastic for brick-in-mastic waterproofing shall be a straight-run residue obtained from the distillation of coal tar and shall meet the following requirements·

* Proposed tentative specifications, Proceedings American Society for Testing Materials, Vol. 17, Part 1, pp. 712–722 (1917).

The melting-point shall be not less than 116 nor more than 122 deg. Fahr. (47 and 50 deg. Cent.), determined by the cube-in-water method. The penetration (Dow machine) at 77 deg. Fahr. (25 deg. Cent.) with 100 grams acting for five seconds, shall be not more than 180 and not less than 110.

The matter insoluble in hot extraction in benzol and toluol shall be not less than 24 and not more than 32 per cent.

The ash shall not exceed 1 per cent.

On distillation to 671 deg. Fahr. (355 deg. Cent.), the specific gravity of the total distillate shall be not less than 1.06, determined at 140/140 deg. Fahr. (60/60 deg. Cent.).

Remarks. Coal-tar pitch meeting the above specifications has not yet been used for making waterproofing mastic. In fact, no coal-tar pitch has ever been used for the purpose mentioned in the specifications, because it was always considered impossible to obtain a tar-pitch that would be at all plastic at 32 deg. Fahr. (0 deg. Cent.). But as a result of extensive tests a grade of pitch has been evolved in which this objection has been overcome. The above specification is based on that series of tests. The method of making mastic is explained in Chapter II.

Hydrated Lime for Integral Waterproofing.* Hydrated lime is a dry flocculent powder resulting from the hydration of quicklime. It is commercially divided into four classes: (*a*) High calcium; (*b*) calcium; (*c*) magnesian; (*d*) high-magnesian.

The classes and chemical properties of hydrated lime shall be determined by standard methods of chemical analysis.

The non-volatile portion of hydrated lime shall conform to the following requirements as to chemical composition:

CHEMICAL COMPOSITION OF HYDRATED LIME

Properties Considered.	High Calcium.	Calcium.	Magnesian.	High Magnesian.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Calcium oxide	90 (min.)	85–90	.....	.....
Magnesian oxide	.....	.....	10–25	25 (min.)
Silica alumina oxide of iron (max.)	5	5	5	5
Carbon dioxide (max.)	5	5	5	5
Water	Sufficient to hydrate the calcium-oxide content.	Sufficient to hydrate the calcium-oxide content.	Sufficient to hydrate the calcium-oxide content.	Sufficient to hydrate the calcium-oxide content.

* Book of American Society for Testing Materials Standards, p. 472, 1916.

A 100-gram sample shall leave by weight a residue of not over five (5) per cent on a standard 100-mesh sieve and not over 0.5 per cent on a standard 30 mesh-sieve.

Hydrated lime shall be tested to determine its constancy of volume in the following manner:

Equal parts of the hydrated lime under test and volume-constant Portland cement shall be thoroughly mixed together and gaged with water to a paste. Only sufficient water shall be used to make the mixture workable. From this paste a pat about 3 inches in diameter and $\frac{1}{2}$ inch thick at the center, tapering to a thin edge shall be made on a clean glass plate about 4 inches square. This pat shall be allowed to harden twenty-four hours in moist air and shall be without popping, checking, cracking, warping or disintegration after five hours' exposure to steam above boiling water in a loosely closed vessel.

The sample shall be a fair average of the shipment. Three per cent of the packages shall be sampled. The sample shall be taken from the surface to the center of the package. A 2-pound sample to be sent to the laboratory shall immediately be transferred to an air-tight container, in which the unused portion shall be stored until the hydrated lime has been finally accepted or rejected by the purchaser.

Hydrated lime shall be packed either in cloth or in paper bags and the weight shall be plainly marked on each package.

The name of the manufacturer shall be legibly marked or tagged on each package.

All hydrated lime shall be subject to inspection.

The hydrated lime may be inspected either at the place of manufacture or the point of delivery, as arranged at the time of purchase.

The inspector representing the purchaser shall have free entry at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the hydrated lime ordered. The manufacturer shall afford the inspector all reasonable facilities for inspection and sampling, which shall be so conducted as not to interfere unnecessarily with the operation of the works.

The purchaser may make the tests to govern the acceptance or rejection of the hydrated lime in his own laboratory or elsewhere. Such tests, however, shall be made at the expense of the purchaser.

Unless otherwise specified, any rejection based on failure to pass tests prescribed in these specifications shall be reported within five working days from the taking of samples.

Samples which represent rejected hydrated lime shall be preserved in airtight containers for five days from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

Remarks. The above specifications will be of material aid to the architect and engineer in obtaining a product dependably suitable for waterproofing by the integral method. Though it is claimed that there is little or no difference which grade of hydrated lime is used, still, the following facts have positively been ascertained: The high magnesian lime (25 to 40 per cent magnesia) though it slakes and sets more slowly, takes up less water, generates less heat and expands and shrinks less than the high calcium lime; also that even ordinary magnesian lime (5 to 25 per cent magnesia) works more smoothly and though it also sets slower, it is stronger than high calcium lime.

Specifications for Waterproofing Concrete and Masonry Structures

Specifications for Dampproofing Concrete with Coal Tar. The concrete surface to be dampproofed should be smooth, thoroughly clean and dry. The entire surface should be mopped with a coating of dead oil, using all that the concrete will absorb. If applied in cold weather, the dead oil should be heated; in hot weather it can be applied cold.

The dead oil should conform to the Specifications for Creosote Oil for Priming Coat with Coal-tar Pitch for Waterproofing and Dampproofing, page 270.

When the entire surface is completely mopped with the dead oil, it should be remopped with a straight-run coal-tar pitch, following same with additional moppings until the whole surface has a bright, patent-leather appearance. The coal-tar pitch should conform to the Specification for Coal-tar Pitch for Waterproofing and Dampproofing, page 269.

Both the dead oil and the coal-tar pitch must be delivered on the work in packages that are plainly marked with the manufacturer's brand, and indicating the grade and quality of the material.

Waterproofing Flat Concrete Surfaces with Coal-tar Pitch Mastic. The mastic shall consist of gravel, sand and coal-tar pitch. The materials shall be mixed together in the proportion of three parts of gravel, two parts of sand, and one part of coal-tar pitch by volume. The sand and gravel shall be thoroughly dried, and all materials

heated sufficiently to permit thorough mixing, but in no case shall the temperature exceed 300 deg. Fahr. (149 deg. Cent.).

The gravel shall be from $\frac{1}{8}$ to $\frac{5}{8}$ inch in size.

The sand shall pass 100 per cent through an 8-mesh sieve.

The pitch shall have a melting-point of about 125 deg. Fahr. (52 deg. Cent.) by the cube-in-water method.

The mixture shall be spread over the surface to the required thickness, compacted either by tamping or rolling, and given a mopping of coal-tar pitch the same as is used in the mixture.

If ballast is to be applied directly on the mastic, the latter should be 2 inches thick. If there is sufficient space to allow for a sand cushion above the mastic, $1\frac{1}{2}$ inches of mastic is sufficient.

Remarks. The above specifications are concise but somewhat incomplete. By specifying a $\frac{1}{4}$-inch (maximum size) gravel; the incorporation of at least one part cement or limestone dust in place of one of the parts of gravel; and more test requirements for the pitch, such as free carbon content, specific gravity of distillate oils and penetration (which would permit identification of the pitch on the work), a more certain grade of mastic would result.

Specifications for Waterproofing Concrete Structures by the Integral Method. Watertightness shall be secured by the addition of *A* * into the mass or by plastering or veneering the interior or exterior of the structure with a continuous coat of waterproofed cement mortar.

Concrete should consist of one (1) part of cement, two (2) or three (3) parts of sand and four (4) or five (5) parts of stone each to meet standard requirements. The quantity of *A* to be used is 8 to 16 pounds per cubic yard of puddled concrete. Introduce the waterproofing at the mixer, by mixing it into water first.

Placing of concrete shall be continuous throughout definite stages and joints between different days' work shall be carefully treated to obtain positive bond.

Cement mortar shall be prepared by thoroughly tempering a dry mixture of one (1) part of cement to either two (2) or three (3) parts of sand with water to which *A* has been added as follows:

Under ordinary conditions 10 pounds per cubic yard of mortar; permanent ground water, 16 to 24 pounds per cubic yard of mortar; ground water pressure, up to 32 pounds per cubic yard of mortar; the mortar to be $\frac{1}{2}$ to 1 inch thick.

The continuous cement coat must be applied in several layers

* These specifications are for the use of a proprietary calcium-oleate compound, herein designated by *A*.

after the underlying concrete has been cleansed of dust and dirt. The concrete surface should be washed with a 10 per cent solution of acid water and afterward rewashed thoroughly with clear water to remove the acid.

The prime or scratch coat is to be well troweled.

The final coat must be floated with a wooden or cork float to avoid air-cushions. The work is to be protected against the rays of the sun or in winter against freezing.

Keep mortar damp so as to prevent too rapid drying.

Remarks. The above specifications are cited merely because they are typical of many of those issued for proprietary integral waterproofing compounds. It is explicit enough, but since no statement of composition or properties of the waterproofing compound is included, what may be expected of the use of the material depends upon the integrity of the manufacturers. In Chapters II and X will be found information which should be consulted before the above type of specifications are accepted as a model by the architect or engineer.

Specifications for Waterproofing Concrete and Masonry Structures by the Integral-mortar Surface Coating Method. It is the intent of these specifications to obtain a watertight structure.

Watertightness shall be secured by plastering the interior surface of the structure with a continuous coat of Portland cement mortar waterproofed with *B* * waterproofing paste.

The mortar composing the plaster coat shall consist of one (1) part of cement and two (2) parts of sand, to meet the following requirements:

The cement shall be a high-grade Portland, which has been carefully tested and found to satisfactorily meet the requirements of the Standard Specifications of the American Society for Testing Materials and preferably ground so that eighty per cent (80%) shall pass a standard two hundred (200)-mesh sieve.

The sand shall consist of spherical grains of any hard rock that is practically free from clay, absolutely free from organic matter, and uniformly graded in size from coarse to fine.

The waterproofed cement mortar shall be prepared by thoroughly tempering (to required consistency) a dry mixture of one (1) part of cement and two (2) parts of sand, with water to which *B* waterproofing paste has been added in the proportion of one (1) part of paste to eighteen (18) parts of water, as directed by the manufacturer.

* These specifications are for the use of a proprietary alum-soap paste compound, herein designated by *B*.

Before plastering the cement mortar on the hardened concrete, the surface of same shall be treated as indicated in the following:

The hardened surface shall be mechanically roughened by chipping and very thoroughly cleaned with a heavy wire broom, so as to remove all dust and dirt. A jet of steam shall be employed to clean the wall, if available.

To the mechanically cleaned surface apply with a large acid brush, a liberal coat of one to ten (1 : 10) solution of hydrochloric acid (muriatic acid). Allow the acid to remain until it has exhausted itself, which will require at least ten minutes. Apply a second coat of acid solution if the first does not sufficiently clean and expose the surface of the aggregate.

With a hose under good pressure, slush the surface so as to remove the salts and loose particles resulting from the action of the acid. Continue the slushing until the old concrete is thoroughly cleaned and soaked to its full capacity. Thoroughly wire-brush the surface so as to remove the particles which have been loosened by the action of the acid.

To the cleaned saturated surface apply with a strong fiber brush a coating of pure cement mixed to a thick creamy consistency with water to which *B* waterproofing paste has been added in the proportion of one (1) part of paste to eighteen (18) parts of water. Rub in vigorously so as to fill all crevices and cavities produced by the action of the acid.

Immediately after applying the above slush coat, the first coat of waterproofed cement mortar shall be applied to a thickness of three-eighths ($\frac{3}{8}$) of an inch directly on the slush coat, and well troweled and rubbed into the crevices of the surface. This first coat shall be lightly scratched before showing initial set. Before this first coat has reached its final set, the second coat shall be applied, of equal thickness, so as to give a full average thickness of three-quarters ($\frac{3}{4}$) of an inch. Special care shall be exercised to apply this finish coat before the first coat has reached its final set. The finish coat shall be thoroughly floated to an even surface and subsequently troweled free from any porous imperfections.

Where water is running through the wall, proper drainage must be provided by drilling holes and inserting tubes in the wall, to concentrate the flow of water. With the pressure relieved, the waterproofed plaster coat shall be applied to the drained portions of the wall. The drainage pipes shall remain open until the waterproofed plaster coat has thoroughly set and is capable of resisting the pressure by its own adhesive strength, when the drainage pipes shall be closed

with suitable plugs and coated with the waterproofed cement mortar.

The floors shall be prepared and treated exactly as indicated above, and finished with a waterproof cement mortar to a thickness of two (2) inches. Special care should be exercised to bond the wall coating to the floor coating, so as to make the waterproofed coating continuous over the entire surface.

When hardened, the waterproofed plaster coat shall be sounded with a light hammer and all loose and defective plaster shall be cut out and replaced.

Remarks. Consistent with proprietary waterproofing materials specifications the one above does not mention anything about the property or quality of the compound specified. Neither is there included a guarantee that the application of this material will make a watertight job for any period of time. On small or unimportant work, the engineer or architect may permit waterproofing under the above type of specifications, but for large or difficult work careful investigation and technical and practical tests are essential. This procedure would undoubtedly tend toward final economy and more certainty of results.

Specifications for Waterproofing Cement Stucco by the Integral Method. The materials composing the stucco should consist of: Twelve parts clean sharp sand; one part hydrated lime; five parts standard Portland cement.

The waterproofing paste * should be mixed: One part waterproofing paste; eighteen parts water.

The paste should be dissolved in one part of water to insure a perfect blending, after which add the other seventeen parts water and stir until smooth.

The cement and hydrated lime should be mixed to a uniform color, before sand is added, then add sand and mix again to a uniform color, after which add the waterproofed water, or " milk " obtained as per preceding paragraph. This mortar must be well " worked " and applied immediately. No mortar should be used after standing more than thirty minutes.

All stucco should be two-coat work. The first coat should be mixed as above with the addition of sufficient long cow hair for keying, when applied to metal lathe. If on masonry, the surface must be saturated with water before applying and the plaster applied before base is dry.

* The waterproofing paste referred to in these specifications is a quasi-soap or quasi-colloidol paste.

After the first coat has been applied it should be roughened so as to form a base for keying the finishing coat, which must be floated in order to densify the plaster.

The finished stucco must be kept wet for four or five days by covering with burlap or other suitable material and sprinkled at least twice a day.

Remarks. The remarks appended to the preceding specifications also apply here. The hydrated lime called for in this specition is of itself an efficient waterproofing agent.

Specifications for Waterproofing Foundations by the Membrane System. The foundation shall be waterproofed, so that the interior will be permanently free from moisture, by a continuous sheet of waterproofing surrounding the exterior and bottom to the height directed by the engineer.

The surface of all masonry upon which the waterproofing is to be applied shall be comparatively smooth and as dry as is practicable.

Coat the entire surface on which the waterproofing is to be applied with tar pitch,* into which, while hot, imbed a layer of treated felt,† following this with alternating layers of felt and pitch until five layers of felt and six moppings of pitch have been applied. All felt must be bedded into the pitch while the latter is still hot but in no place shall felt touch felt.

At all wall angles, corners and any place where in the opinion of the engineer the waterproofing course will be subjected to unusual strain, there shall also be used one layer of reinforced felt ‡ and an additional mopping of pitch. Where laps are left to be connected after other work is completed, they shall be not less than 10 inches wide and at least two of the five plies shall be of reinforced felt, and care shall be taken to protect such laps while other work is in progress.

Where waterproofing is applied on the exterior of perpendicular walls, it must be permanently protected by a layer of concrete or course of brick, and until such permanent protection is in place, care must be taken not to break or injure the waterproofing in any way. On horizontal waterproofing the temporary protection must be 1 inch of cement mortar applied immediately after the felt and the pitch are laid.

* A straight-run coal-tar pitch, having a melting-point between 140 and 150 deg. Fahr. by the cube-in-water method.

† A tar-saturated felt of good grade and medium weight.

‡ This reinforced felt is composed of one layer of tar-saturated felt bonded to one layer of unsaturated cotton-woven fabric. This combination is used as a single ply in itself.

On all interior waterproofing, the permanent covering must be of sufficient weight and strength to withstand the maximum water pressure.

Specifications for Waterproofing Subsurface Structures by the Integral Motor Surface Coating Method. Waterproofing shall consist of cement mortar facings waterproofed with *C*.* These facings (or coatings) shall be applied to those surfaces of walls (interior or exterior below grade); upper surface of floor slabs; basement and sub-basement; pits, tunnels, etc., where waterproofing is indicated in plans and specifications.

The mortar for these facings shall be composed of one part of cement of brand approved by architect, two parts of clean sharp sand, to which shall be added $1\frac{1}{2}$ gallons of *C* for each bag of cement.

These waterproof facings shall be from $\frac{3}{4}$ to 1 inch applied in at least two coats on walls and not less than 1 inch thick applied in one coat on floor surfaces. The finish coat shall be well floated to close all pores.

Thoroughly mix the cement and sand dry.

Put enough *C* for one batch into an empty barrel and add a small quantity of water, stirring until entirely smooth. Then stir in more water, but not more than will be required to give a stiff mortar.

Mix this liquid in the cement and sand as usual, turning over until the color of the mortar is uniform.

The measured amount of *C* may be added to the charge in a batch mixer without first dissolving in the gaging water; no more than the usual time of mixing is needed.

Where the masonry is new, clean and rough, it is necessary merely to saturate the surface with water. It is very important to use as much water as the surface will take up; otherwise the mortar will be sucked dry before it has a chance to set properly.

Old surfaces, such as smooth concrete, brick-work, stone, etc., must be chipped, bush-hammered or sand-blasted until suitably rough; rubbed with a wire scratch-brush to remove loose particles, paint, slime, etc.; washed with dilute muriatic acid (mixed one to four in a wooden pail), and finally flushed down with clean water to remove all traces of acid. After seeing that the wall is saturated with water, the mortar must be applied as soon as possible.

Over a very hard, seasoned concrete, a thin cement wash, applied before the mortar coat, and allowed to harden slightly, will promote the adherence of the new mortar.

* These specifications are for the use of a proprietary asphaltic-emulsion paste compound, herein designated by *C*.

C waterproofing compound will not make up for careless or unskilled labor. The precautions of ordinary good practice must be observed in every point, just as if *C* were not used.

Remarks. The company issuing the above specifications is frank enough to admit that the material it specifies will not make up for careless or unskilled labor, and that the precautions of good practice must be observed in every point if the waterproofing material is to be effective. In Chapters II and X will be found facts and figures showing what may be accomplished by the use of experienced labor and careful supervision without the addition of any integral waterproofing, if the importance of the work warrants the expense of these extra precautions.

Specifications for Waterproofing Tunnels and Subways

Specifications for Waterproofing New York Subways * by the Membrane and Brick-in-mastic Systems. *General Directions.* In general, waterproofing of the structure will be limited to the roof and to those surfaces near ground water or mean high water if ground-water level is found for any reason to be below mean high water. At other places free drainage shall be provided by pipe drains, hollow tile or broken stone.

At the stations the entire structure shall be waterproofed.

The protecting masonry shall be concrete, common bricks or hollow terra-cotta blocks as directed, and shall be not less than four (4) inches in thickness.

In places where permanent sheeting is placed at the waterproofing line, the waterproofing, if permitted by the engineer, may be applied against the sheeting.

All surfaces to which waterproofing is to be applied shall be made as smooth as possible; on these surfaces there shall be spread hot melted coal-tar pitch in a uniformly thick layer; on this layer of pitch shall be laid a treated woven fabric of such material as may be approved by the engineer; this process shall be repeated until such number of layers as may be required by the engineer have been placed and a final coat of the pitch shall then be applied.

The term " ply " as used in these specifications shall mean a layer of treated woven fabric (except the dry-ply), both sides of which shall be coated with coal-tar pitch at the time of laying.

The number of plies of waterproofing over the roof between sta-

* Dual Subway System built under supervision of Public Service Commission for the First District, State of New York, D. L. Turner, Chief Engineer.

tions shall in no case be less than three (3), except as hereinafter provided where brick laid in asphalt mastic is used.

On the sidewalls at the station the same conditions as in the preceding paragraph shall apply.

On the sides and bottom of the structure below a line two (2) feet above ground water, or, if ground water is below mean high-water level, then (2) feet above mean high water, one (1) ply of waterproofing, as described above, shall be used with one or more courses of brick laid in asphalt mastic; the number of courses of brick to be determined by the engineer.

The requirements in the preceding paragraphs of this section likewise shall apply to the roof of the structure within station limits and over the tracks passing through the station within said limits.

The quality of brick used for brick-in-mastic waterproofing shall be the best quality common brick, burned hard entirely through, regular and uniform in shape. The brick shall be properly dried and shall be heated before laying.

Six (6) plies of waterproofing fabric may be substituted for brick-in-asphalt-mastic, if approved by the engineer, and will be paid for as provided for fabric waterproofing.

Asphalt mastic shall contain not less than one-third ($\frac{1}{3}$) asphalt, the other ingredients to be sand and limestone dust or sand and cement. The ingredients are to be in proportions governed by local requirements and weather conditions. In melting and mixing the mastic its temperature shall not exceed 350 deg. Fahr. (177 deg. Cent.)

Any masonry that is found to leak at any time prior to the completion of the work and final acceptance thereof shall be cut out and the leak stopped, at the sole expense of the contractor.

Both the coal-tar pitch and the asphalt must be delivered on the work in packages that are plainly marked with the manufacturer's brand, and indicating the grade and quality of the material.

The coal-tar pitch shall be straight-run pitch containing not less than twenty-five (25) per cent and not more than thirty-two (32) per cent of free carbon, which will soften at approximately 70 deg. Fahr. (21 deg. Cent.), and melt at 120 deg. Fahr. (49 deg. Cent.) (by the cube-in-water method) being a grade in which distillate oils distilled therefrom shall have a specific gravity of 1.05.

The asphalt used shall consist of fluxed natural asphalt, or asphalt prepared by the careful distillation of asphaltic petroleum, subject to the approval of the engineer, but however prepared, it shall comply with the following requirements:

The asphalt shall contain in its refined state not less than ninety-five (95) per cent of bitumen soluble in cold carbon disulphide, and at least ninety-eight and one-half ($98\frac{1}{2}$) per cent of the bitumen soluble in cold carbon disulphide shall be soluble in cold carbon tetrachloride. The remaining ingredients shall be such as not to exert an injurious effect on the work.

The asphalt shall not flash below 350 deg. Fahr. (177 deg. Cent.) when tested in the New York State Closed Oil Tester. When twenty (20) grams of the material are heated for five (5) hours at a temperature of 325 Fahr. (163 deg. Cent.) in a tin box two and one-half ($2\frac{1}{2}$) inches in diameter, it shall not lose over three (3) per cent by weight, nor shall the penetration at 77 deg. Fahr. (25 deg. Cent.) after such heating be less than one-half ($\frac{1}{2}$) of the original penetration.

The consistency shall be determined by the penetration which must be between 75 and 100 at 77 deg. Fahr.

The melting-point of the material shall be between 115 and 135 deg. Fahr. (46 and 57 deg. Cent.) as determined by the Kraemer and Sarnow method.

Penetrations indicated herein refer to the depth of penetration at 77 deg. Fahr. in hundredth centimeters of a No. 2 cambric needle weighted to one hundred (100) grams acting for five (5) seconds.

A briquette of the solid bitumen of cross-section of 1 sq. cm. shall have a ductility of not less than twenty (20) cm. at 77 deg. Fahr. the material being elongated at the rate of five (5) cm. per minute. (Dow molds.)

All tests herein specified must be conducted according to methods approved by the engineer.

The fabric to be used shall be a woven fabric which shall have been treated with coal-tar pitch or asphalt before being brought on the work. The fabric * and the material used in its treatment shall be approved by the engineer.

All concrete shall be dry before waterproofing is attached. If, in the judgment of the engineer, it is impracticable to have the concrete dry, then there shall be first laid a layer of treated felt of approved quality, on the upper surface of which is to be spread the first layer of pitch or asphalt.

Each layer of pitch or asphalt must completely and entirely cover the surface on which it is spread without cracks or blow holes.

The fabric must be rolled out into the pitch or asphalt while the

* For fabric specifications, see p. 265.

latter is still hot, and pressed against it so as to insure its being completely stuck over its entire surface, great care being taken that all joints are well broken by overlapping, and that, unless otherwise permitted, the ends of the rolls of the bottom layers are carried up on the inside of the layers on the sides, and those of the roof down on the outside of the layers on the side so as to secure a full lap of at least one (1) foot. Especial care must be taken with this detail.

When the finishing layer of concrete is laid over or next to the waterproofing material, care must be taken not to break, tear or injure in any way the outer surface of the pitch or asphalt.

None but competent men, especially skilled in work of this kind, shall be employed to lay the waterproofing.

Standard Specifications for Waterproofing the Philadelphia Subways by the Sheet-mastic, Brick-in-mastic and Membrane Systems. It is the intent of these Specifications * to secure a subway structure that shall be entirely free from percolation of outside water, and the contractor shall do all the work in such manner and take such precautions as will secure this result and shall guarantee the watertightness of the work for three (3) years. Surfaces shall be hard and dry before any waterproofing is attached, and shall first be coated with an asphalt paint made from the asphalt herein specified diluted with 42 deg. Baumé naphtha to the proper consistency and free of oil. If for any reason it is impracticable to have the surface dry, and the engineer so orders, there shall first be applied one (1) layer of double-thick roofing felt.

The waterproofing shall be done as follows:

The roof shall be waterproofed with two (2) layers of asphalt mastic, each one-half ($\frac{1}{2}$) inch thick, and protected on top by three (3) inches of 1 : 3 : 6 concrete.

The floor or invert shall be waterproofed with one (1) ply of treated fabric in compound and two (2) courses of hard brick, laid flat in compound, all laid on a bottom course of 1 : 2 : 4 concrete.

The side walls shall be waterproofed with one (1) ply of fabric treated in compound, against four (4) inches of 1 : 3 : 6 concrete, four (4) inches of hollow tile brick or the concrete sheathing of the trenches. Against the fabric shall be laid eight and one-half ($8\frac{1}{2}$) inches of brick dipped in compound. The sidewall treatment shall extend up to an elevation two (2) feet above ground water line.

The asphaltic compound to be used for waterproofing or for the

* Standard Specifications for Construction of Subway Structure; Dept. of City Transit, City of Philadelphia, January, 1917.

preparation of mastic shall be composed of fluxed refined natural lake asphalt, or of asphalt obtained by the distillation of asphaltic petroleum. It shall contain at least ninety-five (95) per cent of bitumen soluble in carbon disulphide (CS_2), shall have a melting-point between 150 and 180 deg. Fahr. by the cube method, and a ductility at 40 deg. Fahr. of at least 5 cm., and at 77 deg. Fahr. of at least 20 cm. by the Dow method. The mastic shall be prepared on the work by thoroughly mixing with the asphaltic compound properly graded limestone dust and sand, at a temperature between 300 and 375 deg. Fahr., so as to make a homogeneous mass. The mastic shall be proportioned as follows:

Soluble bitumen, 12 to 18 per cent as may be found necessary;
Mineral aggregate passing 200-mesh screen, 25 to 30 per cent;
Mineral aggregate passing 50-mesh screen, 20 to 30 per cent;
Mineral aggregate passing 4-mesh and retained on 10-mesh screen, 20 to 30 per cent.

Coal-tar pitch, if used for either fabric waterproofing or for the " brick in compound " method, shall be straight-run residue from the distillation of coal tar. It shall have at least seventy-five (75) per cent of bitumen soluble in benzol (C_6H_6), a melting-point between 120 and 140 deg. Fahr., and a ductility at 40 deg. Fahr. of at least 5 cm. Where coal-tar pitch is to be used for waterproofing, the sizing paint to be applied to the concrete surfaces in advance of the waterproofing shall be raw coal-tar.

The plans show the invert and sidewalls of the subway structure waterproofed, where waterproofing is expected to be necessary, by brick laid in compound, but all or part of this work may be ordered to be done by using one or more plies of the fabric waterproofing.

The brick used in waterproofing shall be straight and hard, of the quality prescribed for " Brick Masonry." The floor and sidewalls of the subway structure shall be waterproofed in the following manner: The excavation for the subway floor shall be made to the proper grade and thereon shall be placed a layer of 1 : 2 : 4 concrete, troweled smooth on top. After this concrete has set and is hard there shall be spread on it a complete layer of the hot compound described above, as thick as is workable, without cracks or blow holes. One (1) layer of the treated fabric shall be spread on the coated surface while the compound is still hot and be pressed flat against its entire surface with an electrically heated iron, so that it shall firmly adhere to the surface without bubbles or air spaces. The exposed surface

of the fabric shall then be completely coated with hot compound. On this surface two (2) courses of brick shall be laid flat. The brick shall have previously been dried, and while warm shall be dipped in compound and laid on a bed of the compound on the coated fabric. The compound shall completely fill the spaces between the bricks and the top course finished off with a thin layer of the compound. The waterproofing shall be continuous and extend around all projections of the invert and sidewalls of the subway. Upon the coated brick laid on the invert there shall be built at the sides the waterproofing for the sidewalls by placing one (1) ply of treated fabric as herein described against the concrete sheeting, or against four (4) inches 1 : 3 : 6 concrete or hollow-tile masonry. Against this coated layer of fabric there shall be laid eight and one-half ($8\frac{1}{2}$) inches of dried warm brick, dipped in hot compound and laid in compound while hot. The bricks shall break joint, and the spaces between the bricks be completely filled with compound.

The fabric shall be an approved woven cotton cloth, weighing before treatment, not less than 5 ounces per square yard; with at least thirty (30) threads per inch. It shall be thoroughly saturated with the asphaltic compound described above before laying, shall have no admixture or coating of mineral or other matter, and shall weigh after saturation not less than fourteen (14) ounces per square yard. The term " ply " shall be understood to mean a layer of woven cotton fabric saturated with compound before laying, with a layer of compound on each side of it applied in laying. A complete layer of hot compound as thick as is workable shall be evenly spread on the surface to be waterproofed, without cracks or blow holes. The fabric shall then be spread on the coated surface while the compound is still hot, and be pressed flat against its entire surface with an electrically heated iron, so that it shall firmly adhere to the surface without bubbles or air spaces. The exposed surface of the fabric shall then be completely coated with the hot compound. Where steel or concrete sheathing is placed at the waterproofing line, the waterproofing from the floor line to two (2) feet above ground water line shall be applied against the sheathing.

Asphaltic material shall be delivered to the work in original packages, marked with the manufacturer's name and brand, and indicating the grade and quality of the material.

Where holes or void spaces are to be filled or built in after the removal of temporary posts, shores or braces, the utmost care shall be taken to bond the new concrete or other material to the prior

work, and to make the placing of patches of waterproofing continuous and watertight. The contractor shall execute his work in such a manner as to eliminate as far as possible such patchwork.

Every care shall be exercised not to puncture or otherwise injure the waterproofing after it is in place and when applying the protecting masonry. If any leaks are found before the completion of the work, the defective portions shall be cut out and efficiently repaired.

Only competent men skilled in this particular class of work will be permitted to do the waterproofing. The contractor will be required to guarantee the efficiency of waterproofing by the rendering of watertight structure during the three-year period for maintenance.

Waterproofing shall not be done when exposed to wet weather, nor to a temperature below 40 deg. Fahr., and it shall be applied only when the surface to be treated is perfectly dry.

Remarks. The above specifications refer to the method of determining the melting-point of bitumen as the " cube-method "; there are two distinct methods for finding the melting point of bitumens that fall under this head; one is the " cube-in-air," the other is the " cube-in-water " method, the latter giving lower results for the same bitumen and is not as suitable for asphalt. It would be better if the exact method preferred were stated in the specification.

The specifications further call for bricks to be imbedded not in the usual mastic but in pure asphalt. A good mastic is stronger than its constituent asphalt. Mastic is also more substantial than pure asphalt and cheaper as well. For these reasons alone, brick-in-mastic is preferable to brick-in-asphalt.

The specifications permit the use of coal-tar pitch with a melting-point between 120 and 140 deg. Fahr. For waterproofing by the membrane system, coal-tar pitch of this melting-point has been very successfully used on underground work. But mastic made of coal-tar pitch with a melting-point above 120 deg. Fahr. is not suitable for subsurface waterproofing in this climate. On the other hand, if the pitch is intended for use with bricks without incorporating any foreign ingredients it will lack " body " and the bricks will soon rest one upon the other.

One test requirement of coal-tar pitch in the specification is that it should have a ductility of 5 cm. at 40 deg. Fahr. A straight-run coal-tar pitch of the melting-point called for, has practically no ductility at this temperature.

The specifications also call for a woven cotton fabric of a certain

weight, raw and treated; as weight has little bearing on the strength of the material it would seem a better policy to specify a tensile strength. A woven cotton fabric whose ratio of tensile strength in the warp and woof approaches unity, is best for the purpose of waterproofing. The tensile strength in the warp should not be less than 60 pounds per lineal inch.

Specifications for Waterproofing Tunnels on the Pennsylvania Railroad.* It is intended that the interior of waterproof structures shall be permanently free from moisture or discoloration due to the percolation of water or other liquids from outside sources. This end shall be attained by means of a continuous flexible waterproof sheet surrounding the exterior of the structures.

Pitch used shall be straight-run coal-tar pitch, which shall soften at 60 deg. Fahr. (15.5 deg. Cent.) and melt at 100 deg. Fahr. (36 deg. Cent.): being a grade in which distillate oils distilled therefrom shall have a specific gravity of 1.05.

The felt shall be (*trade name and manufacturer given*) or be equally satisfactory to the engineers.

Coal-tar pitch, when applied, shall be at a temperature of not less than two hundred fifty (250) deg. Fahr. (121 deg. Cent.). The pitch shall be mopped on the surface of the masonry to a uniform thickness of not less than $\frac{1}{16}$ inch. Each layer of pitch must completely cover the surface on which it is spread without cracks or blowholes. The felt must be rolled out into the pitch while the latter is still hot and pressed against it so as to insure its being completely stuck to the pitch over its entire surface. Great care must be taken that all joints in the felt are well-broken, and that the ends of the rolls of the bottom layer are carried up on the inside of the layers on the sides, and those of the roof down on the outside of the layers on the sides, so as to secure the full laps herein specified.

Waterproofing must be protected against injury at all times to the satisfaction of the engineers.

Any waterproofed structure that is found to leak at any time prior to the completion of this contract shall be made tight by the contractor in a manner satisfactory to the engineers.

Waterproofing shall consist of six (6) layers of felt and seven (7) layers of pitch alternating, each strip of felt to lap not less than one (1) foot upon the previously laid strip and each section of waterproof sheet shall lap at least one (1) foot with the adjoining section.

Waterproofing will be measured by the square or one hundred (100) superficial feet and paid for accordingly.

* Transactions, American Society of Civil Engineers, Vol. 69, p. 211.

Remarks. The above specification would have increased merit did it not leave the acceptance of materials, the protection of the waterproofing, etc., to the discretion of the field engineer. The engineer's judgment is undoubtedly sound, and his intentions undoubtedly good, but his experience may be very limited in regard to waterproofing and too often he considers waterproofing not a very important item of the work. The properties of waterproofing materials are not a matter of common knowledge as the properties of other construction materials are, neither are systems of waterproofing as standardized as other branches of construction. It seems therefore that the specification writer would be amply justified in receiving the best advice and information regarding these matters and incorporating them in the specification as a help and guidance to the field engineer. The melting-point of the pitch called for in the specifications is indefinite since the method of determining same is not given.

Specifications for Mixing and Placing Grout for Waterproofing Tunnels.* Under this item shall be included the transportation of grouting materials, the operation of grouting plant and all other labor, not specifically included in other items, connected with the mixing and placing of all grout in any part of the work included in this contract, whether such placing is by pouring, by forcing through pipes or by impregnation by use of the grouting pad, under any required pressure not exceeding 300 pounds per square inch. The work to be done under this item shall include all requisite precautions to prevent the setting of grout which may escape upon the exposed surfaces of the masonry, and all measures necessary for the removal of grout which may have adhered to such surfaces and for restoring such surfaces to their original condition.

Grouting will be done to fill all voids in dry packing or elsewhere over the tunnel arch, to close cracks, seams and fissures in the rock about the tunnel or shafts, to increase the imperviousness of the masonry lining, to insure a watertight contact with, and the complete protection of, steel work embedded in the masonry, and for other purposes as required.

Except where it may be ordered to reduce leakage in wet ground, or to increase the stability of shattered, moving or unstable ground, or in connection with sections of masonry lining built to control such leakage or to support such heavy ground, grouting under pressure

* The above specifications are extracted from the general specifications issued by the Board of Water Supply of the City of New York in 1910, for the construction of a portion of the City Tunnel of the Catskill Aqueduct, in the Boroughs of Bronx and Manhattan.

will not generally be ordered under this item, in any place, except in less deep portions of shafts where the external water-pressure is comparatively light, until three months after placing the complete ring of lining masonry at that place. Grouting shall be kept as nearly up with the concreting as the three months' interval permits.

Grout shall be mixed of a consistence suitable to the work in hand, in general as thick as can with certainty be made to completely fill the voids. It is the intention to make grout which is to be forced into pipes not less rich than $1\frac{1}{2}$ parts, by weight, of sand or stone dust to one part of cement. All ingredients shall be entirely free from lumps when put into the mixer. When the grouting of any seam, void, or section of dry packing has begun, it shall, unless otherwise expressly ordered, be prosecuted continuously until completed, without any intermission long enough to allow the grout to take an initial set. In order to insure a complete filling of voids, as in dry packing over the tunnel arch, and to avoid occluding air in the interstices of such dry packing, the grout shall be delivered uniformly and steadily, not in violent spurts or blasts.

By a sufficient number and suitable spacing of grout pipes, by the simultaneous use of a sufficient number of grouting machines, and by changing of connections as required, grouting of dry-packed spaces or of other spaces over the tunnel arch shall be so done, except in cases where the engineer deems it impracticable, that all voids can be filled without requiring any grout to travel more than 25 feet after leaving the grout pipe; and this distance shall be reduced as required. Grouting of any section of tunnel shall begin at the bottom and proceed uniformly upward unless some other order of grouting is directed. In grouting spaces over the tunnel arch through pipes having their upper ends at different elevations, grouting shall invariably begin at the lowest pipes, and no connection shall be made to pipes higher up until the grout has completely filled the space below such higher pipes, as shown by the grout flowing out of them. These spaces, whether dry-packed or not, are to be divided into sections of a length not exceeding 50 feet by masonry cut-off walls built across them and tight against the tunnel roof.

Wherever 50-foot sections over the tunnel arch, or other large voids, are being grouted, such number of grouting machines as may be ordered, generally not less than two, shall be concentrated on each such section or void. Grouting will be considered to be completed, in each case, when no more grout can be forced into the seam, void or dry-packed space under the required pressure up to 300 pounds per square inch.

Regrouting of sections of shaft or tunnel once grouted shall be done if and as required. Water may be ordered forced into pipes for the purpose of opening channels in grout previously placed, or for other purposes, in which case any required pressure up to 300 pounds per square inch shall be applied.

Under the item of sand for grout the contractor shall furnish at some central point natural or artificial sand of the quality below specified, for grout. The specifications for sand for concrete shall apply equally to the sand furnished hereunder, except that the sand for grout is to be of such fineness that 100 per cent will pass a sieve having sixty-four openings per square inch, and 45 per cent will pass a sieve having 1600 openings per square inch, the wires of the sieves being respectively, 0.035 and 0.013 inch in diameter. To obtain this degree of fineness it may be necessary to roll coarser natural sand or stone screenings.

For convenience in handling and measuring into the grouting machine the sand shall, unless otherwise specifilly permitted, be put up in strong sacks each containing a standard weight of sand containing not more than an ordinary degree of moisture (3 to 5 per cent). The quantity to be paid for under this item shall be the number of tons of sand actually mixed in grouting machines, in accordance with order, for grout placed as above specified.

The quantity to be estimated for payment under this term shall be the number of cubic yards of liquid grout actually mixed in accordance with orders. The volume will be computed from the quantities of dry materials, on the assumption that the grout is mixed, in each case, of the consistency established as a standard for that case. The contractor shall keep an accurate tally of the quantities of materials used in grout each day, in each heading or shaft, and shall report such quantities to the engineer not later than the following day. From time to time as the engineer deems necessary, tests will be made to determine the relation between the volume of grout and the quantities of the dry materials, and the estimates will be based upon these tests.

If in the opinion of the engineer there is avoidable waste of grout into the interior of shaft or tunnel, the volume of grout unnecessarily wasted, as estimated by him, shall be deducted from the quantity to be paid for.

Remarks. The process of grouting has been resorted to in several other places throughout the country for sinking shafts in coal mines and salt mines, for waterproofing linings in waterworks tunnels and inverted siphons, for solidifying rock foundations for dams and other

structures; but nowhere has this process been used so extensively, so exhaustively studied and experimented with, and so successfully prosecuted as on the aqueduct grouted under the above specifications. A complete description of the grouting process, the grouting equipment, a history of grouting on various works, and a great deal of other valuable information will be found in the Proceedings of the Brooklyn Engineers' Club, Vol. XIX, page 131, 1915, Brooklyn, New York.

Specification for Waterproofing Pneumatic Caisson.* The floors of shaft caissons (see Fig. 111) shall be waterproofed with six (6) plies of fabric † and seven (7) layers of coal-tar pitch. In order to avoid fumes from hot pitch in compressed air, the fabric shall be made up in normal air in pieces or mats of three plies with coal-tar pitch binder (melting-point 120 deg. Fahr. (49 deg. Cent.) by the (cube-in-water method), each thickness bonding four (4) inches on edges. These triple layers shall be in pieces of convenient size as required by the engineer and shall be passed through the airlock into the air chamber of the caisson. The earth or rock in the bottom of the chamber shall be covered with a layer of concrete, about six (6) inches in thickness, troweled smooth with a coating of mortar containing equal parts, by volume, of cement and sand. Upon this coating shall be spread a layer, not less than one-sixteenth ($\frac{1}{16}$) inch in thickness of soft pitch which will soften at 32 deg. Fahr. (0 deg. Cent.) and melt at about 60 deg. Fahr. (15.5 deg. Cent.) so that it can be spread without heating. Upon this shall be spread a triple layer of fabric with lap of twelve (12) inches on longitudinal joints giving four-ply along the laps, and with lap of eighteen (18) inches on transverse joints. All laps shall be laid in soft coal-tar pitch. The three-ply layer shall be covered with a layer of one-sixteenth ($\frac{1}{16}$) inch of soft pitch, and another three-ply layer of fabric, laid in the manner described, and so as to break joints with the first layer, followed by a final coating of soft pitch. Upon this shall be laid one course of brick, on the flat, in mortar containing equal volumes of cement and sand. Care shall be taken to secure the best obtainable bond between the waterproofing and the metal work of the caissons. Other parts of the railroad which are not lined with cast iron and which are required to be waterproofed in compressed air, may be required to be waterproofed in the manner described above.

* Public Service Commission Specifications for New York Rapid Transit R. R. Route 48, Section 31 (William and Clark St. Tunnel), April, 1914.

† For quality of fabric here referred to, see p. 265.

Before placing the first course of concrete in the floors of shaft caissons, under drains shall be laid to a central sump as directed by the engineer, and all tendency to uplift of the concrete floor shall

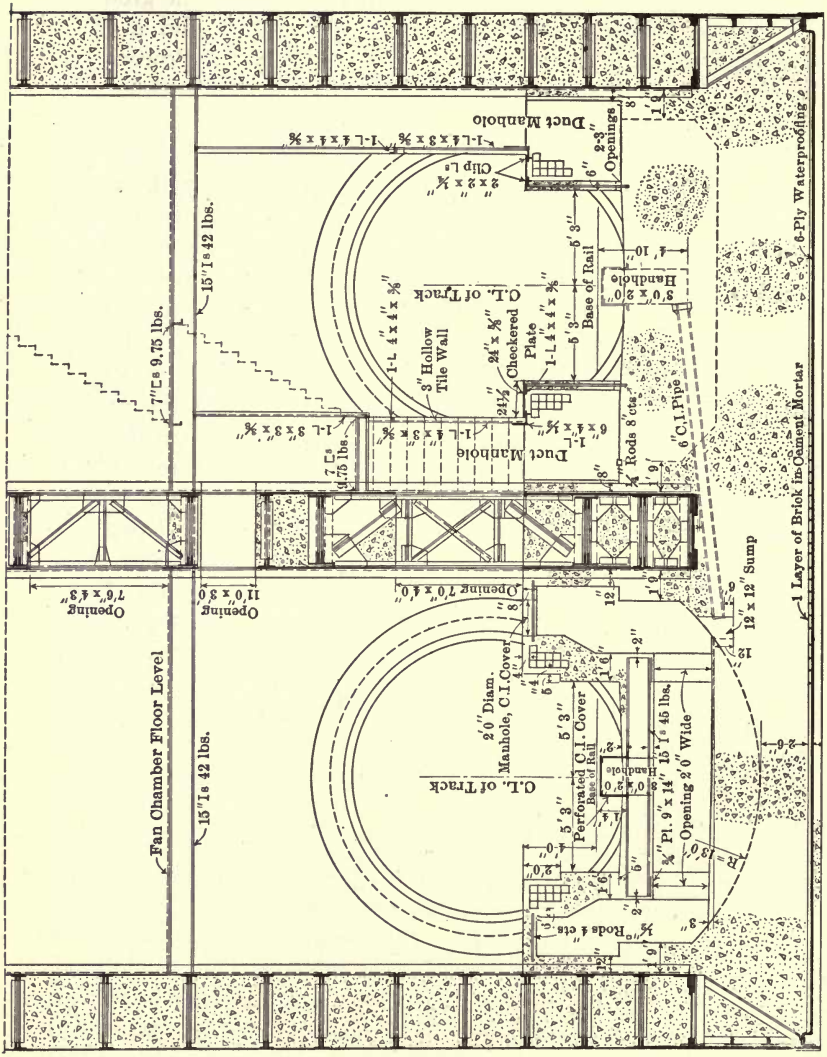


FIG. 111.—Cross-section through Completed Caisson. (Used also as Construction Shaft, as Openings for Ventilating the Tunnels, and to Serve as a Emergency Exit from the Tunnels.)

be prevented by continuous pumping for a period of ten (10) days after the completion of the concrete floor above the waterproofing. The arrangement for pumping shall be such as to prevent drawing sand from beneath the floor. After the expiration of said period of

ten (10) days, pumping from the sump shall be suspended and the sump capped and made watertight and the air pressure gradually reduced to one-half the pressure due to the hydrostatic head. If defects in the waterproofing appear, the contractor shall repair the defects. After a satisfactory test, the concrete filling in the sump shall be completed.

The utmost precautions in regard to fire in the caisson chamber shall be taken at all times while the waterproofing layers of fabric and pitch are exposed, and no lighted candles or matches will be allowed.

Specifications for Waterproofing Railroad Structures

Specifications for Waterproofing Concrete Structures on the Chicago, Milwaukee & St. Paul Railway. The necessary provision for drainage and expansion must be made in designing the structure. The waterproofing should never be compelled to resist hydrostatic pressure, and the membrane should always be protected by a layer of concrete.

Fill all openings and pockets in the concrete, except expansion joints, with cement mortar, and round off all sharp corners. Wherever waterproofing stops on a vertical parapet, the end should be flashed into a groove in the concrete.

Thoroughly clean and dry the concrete surface, using wire brushes and being careful to remove all the laitance. If necessary, use hot sand to dry the concrete. Apply a coat of gasoline to the clean dry surface and follow with a coat of cold primer spreading the primer evenly with a brush. Omit the primer where tar paper is to be placed and over expansion joints.

After the primer coat has completely dried, apply a coat of pure hot asphalt, and mop until the layer has a thickness of $\frac{1}{8}$ inch. While the asphalt is still hot, begin laying the burlap. Lay the first strip of burlap transverse to the drainage at the lowest point. Lay the strips shingle fashion, as for tar and gravel roofs, and parallel to the first strip working up to the summit and exposing one-third of each width of burlap to the weather. Press each strip firmly into the asphalt, then mop well with pure melted asphalt taking care to thoroughly saturate the burlap and to fill all cracks and blow holes. Lap the joints in the strips 6 inches. On this three-ply layer of burlap spread a continuous layer of hot asphalt mopping well until a layer of $\frac{1}{8}$ inch is obtained. See (*f*) Fig. 112.

After the $\frac{1}{8}$-inch layer of asphalt on top of the burlap has become cold spread a $\frac{5}{8}$-inch layer of concrete evenly over the surface. Then press a layer of expanded metal into the concrete and cover the metal with a layer of concrete $\frac{1}{2}$ inch thick making the total thickness of the concrete $1\frac{1}{8}$ inch thick and trowel the concrete smooth.

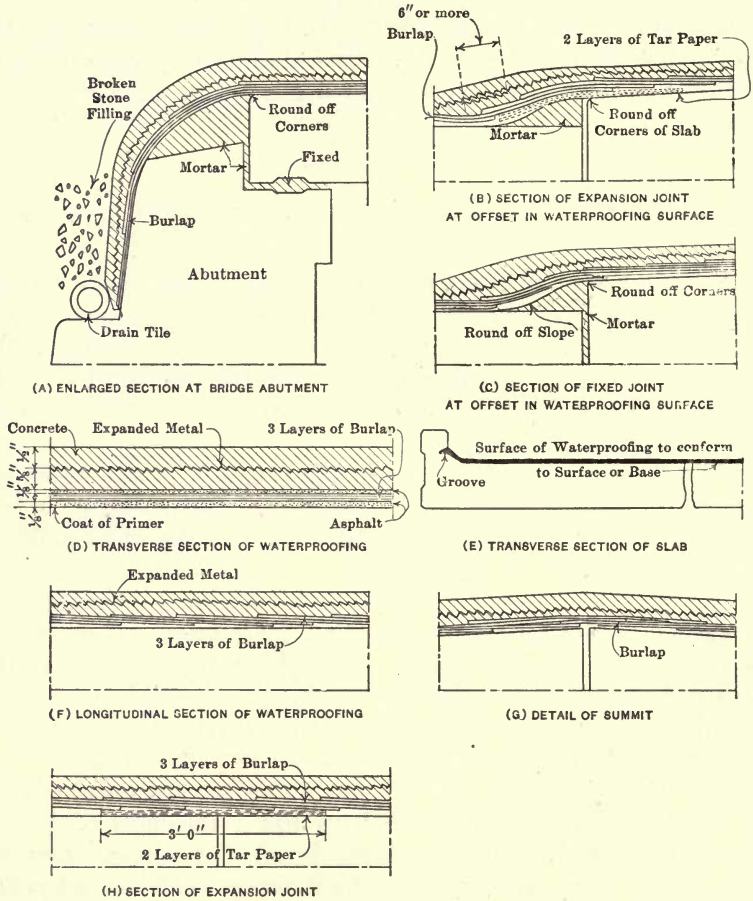


FIG. 112.—Standard Methods of Waterproofing Bridge Floors, C. M. & St. P. Ry.

Protect the concrete from the sun for twenty-four hours after laying. The joints in the expanded metal should be lapped 6 inches. (See (*d*) Fig. 112).

After the work has been brought up to the desired point from both sides, interlap, in order, the strips which reach across the joint, mopping asphalt between burlap surfaces. Place a strip of burlap

along the joint for a closing strip; complete by laying the upper $\frac{1}{8}$ inch of asphalt as before described. See (*g*) Fig. 112.

If possible the waterproofing should be laid in one run the full width transverse to the drain slope of the surface to be waterproofed. The ends of the burlap strip should be flashed into recesses in the walls, curbs or parapets as shown at (*e*). Where longitudinal joints are necessary cut the burlap long enough to extend 12 inches beyond the primed and asphalted surface of the concrete and use care as the strips are laid that the 12-inch strip is kept free from asphalt. When the succeeding section is to be waterproofed, fold back the projecting strips of burlap over the completed waterproofing and bring the new up against the completed portion of the waterproofing, interlapping the projecting ends of the burlap with the new burlap as the work progresses; this is shown at (*f*). On concrete trestle or subway slabs longitudinal joints in the waterproofing should preferably be on the center line of the slabs. If it is necessary to place joints in the waterproofing over joints in the slabs special care should be taken.

Lay two continuous strips of tar paper 36 inches wide over the expansion joint, being careful to see that no asphalt gets between or under the two strips of tar paper. Then mop the top strip with hot asphalt and carry the waterproofing over the top of the paper the same as if no joint existed. See (*b*) and (*h*).

The burlap is to be a treated, 8-ounce, open-mesh burlap furnished in widths of 36 to 42 inches.

The concrete is to be one part Portland cement, two parts torpedo sand and three parts stone or gravel that will pass a $\frac{1}{2}$-inch ring.

The mortar is to be one part Portland cement and two parts washed torpedo sand.

The primer is made by pouring hot asphalt in 80 deg. Baumé gasoline until mixture will spread readily with a brush.

Pure asphalt conforming to accepted specifications is to be used. Before using the asphalt heat it in a suitable kettle to a temperature not exceeding 450 deg. Fahr. (232 deg. Cent.). The temperature is to be taken with a thermometer. Asphalt heated above 450 deg. Fahr. or giving off yellow fumes is to be discarded as overheated.

The expended metal is to be equivalent to (*manufacturer's name stated*) " $2\frac{1}{4}$-inch No. 16 Regular " expanded metal. The tar paper will be furnished in rolls 36 inches wide.

Remarks. In describing the color of fumes coming from the surface of overheated asphalt as being yellow, the author desires to

correct this general misconception and state that the fumes of burned asphalt are bluish black and the fumes of coal-tar pitch are yellow with a greenish tinge.

Specifications for Waterproofing Concrete Structures on the Chicago, Burlington & Quincy Railroad. The waterproofing shall consist of a mat of four ply of burlap and one ply of felt thoroughly saturated and bonded together with waterproofing asphalt and covered with 1 inch of sand-and-asphalt mastic. No waterproofing shall be done when the temperature is less than 60 deg. Fahr. (15.5 deg. Cent.).

The surface of the concrete shall be smooth, clean and dry. Upon this surface there shall first be applied, with brushes, a coat of priming paint, which shall be thin enough to penetrate the concrete and form an anchorage for the waterproofing.

After this priming coat has dried, a heavy coat of waterproofing asphalt, heated to a temperature of 400 deg. Fahr. (204 deg. Cent.), shall be applied with mops, the width of the burlap, and while this is still hot a layer of burlap shall be bedded in it. The burlap shall be laid just behind the mopping and swept with a broom, and must be free from folds and pockets. The surface of this burlap shall be heavily mopped with waterproofing asphalt, and three more ply laid in the same manner, making a four-ply burlap mat all thoroughly saturated and bonded together. The top of the burlap mat shall be heavily mopped and one thickness of felt saturated with asphalt laid on it, the edges lapped at least 3 inches, and sealed with asphalt. The top of this felt shall also be mopped with waterproofing asphalt. This shall then be covered with 1 inch of asphalt mastic laid in one layer, the mastic to be composed of one part of waterproofing asphalt and four parts of fine gravel graded from $\frac{1}{4}$ inch to fine sand, the top leveled off with wooden floats and mopped with a heavy coat of asphalt.

At all the expansion joints in the concrete a fold, to allow for the expansion of the structure, shall be formed by laying the burlap and felt over a 1-inch pipe and removing the pipe as the mat is being completed.

Where the work is stopped before being completed, at least 3 feet of burlap at the end and half the width of the burlap at the side shall be left exposed to form a splice. Special care shall be taken to seal the waterproofing at the sides and ends of the bridge. The burlap and mastic shall be carried up the parapet walls at the sides and the ends concreted in a recess in the walls so that no water can enter. The burlap shall be carried down over the back walls at the ends of

the bridge to cover all construction joints and shall run into a line of tile to facilitate the escape of the water.

The burlap shall be 8-ounce, open-mesh, high-grade burlap saturated with an asphalt meeting the specifications for waterproofing asphalt. It shall come in rolls which shall be placed on end for shipment and storage, and shall not stick together in the roll. The felt shall be a good quality wool felt, saturated and coated with an asphalt meeting the specifications for waterproofing asphalt. It shall come in rolls, which shall be placed on end for shipment and storage, and shall not stick together in the roll. It shall not weigh less than 15 pounds per 100 square feet. The primer shall be an asphaltic compound of approved quality and capable of adhering firmly to the concrete.

The waterproofing asphalt shall meet the following requirements: (1) The specific gravity of the asphalt desired shall be greater than 0.95 at 77 deg. Fahr. (25 deg. Cent.). (2) The flowing-point shall not be less than 130 deg. Fahr. (54.5 deg. Cent.) nor more than 140 deg. Fahr. (60 deg. Cent.). (3) The flash point shall not be lower than 450 deg. Fahr. (232 deg. Cent.). (4) The penetration at 80 deg. Fahr. (27 deg. Cent.) for a period of thirty seconds shall be at least 15 mm. and must not exceed 20 mm. This penetration to be measured with a Vicat needle weighing 300 grams, one end being 1 mm. in diameter for a distance of 6 cm. (5) When heated to a temperature of 325 deg. Fahr. (163 deg. Cent.) for seven hours the loss in weight shall not exceed 2 per cent and the penetration of the residue at 80 deg. Fahr. and for the period of thirty seconds using the same instrument as described above shall not be reduced more than 50 per cent. (6) The total soluble in carbon disulphide shall not be less than 99 per cent. (7) The total soluble in 88 deg. naphtha shall not be less than 70 per cent. (8) The total inorganic matter or ash shall not exceed 1 per cent. (9) Cold test. (*a*) A cube of asphalt 1 inch on edge shall be soft and malleable at a temperature of 0 deg. Fahr. (−18 deg. Cent.). (*b*) A film of the asphalt having a thickness not less than $\frac{1}{16}$ inch shall be so pliable at 0 deg. Fahr. that it can be bent in a radius of 2 inches. The total time consumed in the bending of this film shall not exceed three seconds. (10) The asphalt shall not be affected by any of the following solutions, after being immersed in them for a period of three days: (*a*) A 25 per cent solution of sulphuric acid; (*b*) a 25 per cent solution of hydrochloric acid; (*c*) a 20 per cent solution of ammonia.

Remarks. The above specification differs from the previous one mainly in that it specifies a 1-inch thickness of asphalt mastic as a

protective coat over the membrane. This is good practice but it requires very careful selection of materials, and good workmanship in its preparation and application for the best results. In describing the testing of the waterproofing asphalt, no mention is made of the method of determining the flowing-point. Besides, from the temperature given, it is evident that the melting-point is meant, and not the flowing-point, because the flowing-point is only a comparative test.*

Limiting the work of waterproofing to an atmospheric temperature of 60 deg. Fahr. is at least 20 deg. too high and therefore too restrictive a clause. A surface-coating of sand on top of the mastic is an advisable requirement, as this tends to prevent abrasion of the surface by the ballast.

Specifications for Waterproofing Solid-floor Railroad Bridges.† The depth of steel or concrete construction shall be such as to allow a sufficient distance from top of rail to top of steel or concrete floor for proper waterproofing and protection from the cutting action of the ballast. Under ordinary conditions, a depth of from 3.5 to 4.0 feet from top of rail to clearance line below is sufficient.

Provision shall be made for grades of at least 1 per cent on the floor of the bridge to remove water promptly. Where this cannot be done in the steelwork, cement mortar, with a minimum thickness of $2\frac{1}{2}$ inches, shall be placed so as to drain the water to the inlets.

Cast-iron inlets shall be set at proper places in the floor and provided with movable top grates. The down-spout from each inlet shall be provided with a trap and cleanout, which shall be accessible from below the bridge. The down-spout shall be of wrought iron, and connected to a sewer or arranged according to local conditions.

On top of the prepared surface of the concrete shall be placed either of the following:

1. One or more thicknesses of felt or fabric, of quality and applied as specified hereafter, together with proper protection.
2. Asphalt mastic at least $1\frac{1}{2}$ inches in thickness, of quality and applied as specified hereafter.

Felt, Burlap or Fabric. When waterproofing material of this kind is to be used, either of the following types shall be adopted:

1. From four to six layers of felt.
2. One middle layer of treated burlap, with four layers of felt.
3. One layer of felt, two layers of burlap, and two layers of felt.

* See Chapter VII on Flow-point Test.

† Proceedings, American Society of Civil Engineers, Vol. 40, No. 10.

4. One middle layer of treated burlap, and two layers of asbestos felt.

5. Either one or two layers of treated cotton-drill fabric.

After the completion of the felt or fabric waterproofing, the entire surface shall be covered and protected by one of the following methods:

1. Straight, hard-burned brick laid flat, with joints filled either with waterproofing compound or cement grout. (Waterproofing compound should only be used as a filler on flat or nearly flat surfaces.)

2. A layer of concrete from 2 to $2\frac{1}{2}$ inches thick with wire reinforcement.

3. A layer of about $1\frac{1}{2}$ inches of asphalt mastic used only on top of asbestos felt.

On top of the protection coat, and outside the line of the ties, a line of half-round cast-iron pipe, 6 inches in diameter, and perforated frequently, shall be placed to collect the water and convey it to the inlets.

All openings in the steelwork shall be thoroughly closed, either by calking with burlap dipped in hot asphalt, or by the use of sheet metal sufficient to maintain the concrete base before applying the burlap and asphalt.

Wherever called for by the plans, the decks of the bridges shall be protected with 1 : 3 : 5 concrete, with $\frac{3}{4}$-inch stone or gravel, mixed as specified hereafter, finished with a 1 : 2 mix of cement mortar, $\frac{1}{2}$ inch thick, troweled to a smooth surface on top. This concrete shall be allowed to dry thoroughly so as to prevent the formation of steam when the hot waterproofing materials are applied.

All vertical or sloping surfaces of concrete or steel shall be cleaned of dust, dirt, loose particles, paint, and grease. The use of a hand-bellows is recommended for cleaning loose dust and dirt from the surfaces. For cleaning paint and grease from the steel and freshening the surfaces of asphalt, where a junction of old and new is to be made, or where a pocket of pure asphalt is used against the girders and the felt or mastic, gasoline shall be used, either by swabbing the surface with it, or by pouring a small quantity over the surface to be cleaned and setting fire to it. The use of a blow-lamp is also recommended.

These surfaces shall then be painted with two coats of approved asphalt, diluted with gasoline. The materials of the first coat shall be proportioned so as to give a brownish tint. The second coat shall have a larger quantity of asphalt.

Both coats of paint shall be thoroughly applied and worked into the surfaces, so as to give a uniform coating of the asphalt.

Paint shall not be applied to damp concrete or steel. The painting shall be done immediately in advance of the application of the waterproofing materials and before dust has had time to collect.

If the concrete is damp before the waterproofing is applied, the surface shall be first covered with a 2-inch layer of hot sand and allowed to stand for from one to two hours, after which the sand shall be swept back, uncovering sufficient surface to begin work, and the operation repeated over a new surface.

All concrete shall be of such consistency that when dumped in place it shall not require much tamping, and shall be laid with a view to be an aid to the watertightness of the structure, and not merely a support for the waterproofing materials. All showing surfaces shall be troweled to a smooth, hard surface.

In cases where concrete haunching against girders is called for by the plans, forms shall be used, and the concrete shall be of a wet consistency.

On the prepared surface, apply the specified number of layers of approved saturated and coated felt (with a finished surface) weighing about 14 pounds per 100 square feet.

The bids shall be based on the use of the type of felt specified in the above paragraph, but additional alternate bids will be considered, based on felts or fabrics other than these, which may be approved by the chief engineer. In the event of such alternate bids being made, the bidders shall present with them sufficient data as to the methods of manufacture, quality of materials, and references to places where such felts or fabrics have been used, giving dates of application.

All materials shall be delivered on the work in their original packages, and properly branded.

The asphalt used shall consist of fluxed natural asphalt, or asphalt prepared by the careful distillation of asphaltic petroleum.

It shall contain, in its refined state, not less than 98 per cent of bitumen soluble in cold carbon-disulphide. The remaining ingredients shall be such as not to exert an injurious effect on the work.

When 20 grams are heated for five hours at a temperature of 325 deg. Fahr. (163 deg. Cent.) in a tin box $2\frac{1}{2}$ inches in diameter, it shall not lose more than 2 per cent by weight, nor shall the penetration at 77 deg. Fahr. (25 deg. Cent.) after such heating, be less than one-half of the original penetration. The consistency shall

be determined by the penetration, which must be between .75 and 1.00 cm. at 77 deg. Fahr.

The penetration indicated herein refers to the depth of penetration, in hundredths of a centimeter, of a No. 2 cambric needle, weighted to 100 grams, at 77 deg. Fahr., acting for five seconds.

The melting-point shall be between 150 deg. and 190 deg. Fahr. (66 and 88 deg. Cent.).

A briquette of the solid bitumen, having a cross-section of 1 sq. cm., shall show ductility at 40 deg. Fahr. (4 deg. Cent.) and at a temperature of 77 deg. Fahr. shall show a ductility of not less than 20 cm., the material being elongated at the rate of 5 cm. per min. (Dow molds.)

All flashing and reinforcing around inlets and other places specified shall be carefully executed.

Waterproofing shall not be done in wet weather, or at a temperature below 32 deg. Fahr., without special orders from the chief engineer. The felt shall be laid shingle fashion, the first two layers longitudinally and the last three transversely to the center line of the bridge, where five layers are called for, and as specified in detail in other cases, and shall be carried up the haunching and made secure against the girder in a satisfactory manner. The flashing against vertical or inclined surfaces shall be in accordance with the directions of the chief engineer, if not indicated on the plans. The first layer of felt shall not be cemented to the floor of a steel bridge, except around the drain outlets. On an arch bridge, the first layer shall be cemented to the top of the arch. At no point shall there be less than the specified number of thicknesses.

As the hot asphalt is spread, the felt shall be immediately rolled into it, rubbed and pressed over the surface so as to eliminate air bubbles and insure thorough sticking. One mopful of the asphalt shall not be spread over more than 1 square yard of surface at one mopping. Not less than 2.5 to 3 gallons of asphalt shall be used on 100 square feet of a single layer of felt. The top layer shall also be mopped and the work done so that the layers shall be one compact mass.

The finish of the waterproofing against the girders or concrete shall be made with a pocket of pure elastic asphalt of the quality specified above, except that the melting-point shall be between 140 and 180 deg. Fahr. (69 and 82 deg. Cent.), the ductility at 40 deg. Fahr. shall be at least 3 cm. and the adhesive qualities shall be satisfactory to the chief engineer. The surfaces with which this material comes in contact shall be dry, absolutely free from dust or

grease, and, previous to its application, shall be covered with a thin paint made by dissolving the asphalt in gasoline.

Particular care shall be taken to make a tight joint around gussets, stiffeners, and the ends of girders.

Care shall be taken to prevent injury in any way to the waterproofing by the passing of men or wheelbarrows over it, or by throwing any foreign materials on it.

After the waterproofing course has been completed, the horizontal surfaces shall be protected by a course of straight, hard-burned and dense brick, laid flat in a bed of 1 to 3 cement mortar, with full joints. There shall be not less than $\frac{1}{2}$ inch of mortar between the felt and the bricks. The brick shall not increase in weight more than 10 per cent when immersed in water for seven hours.

The haunching, and about 18 inches in width of the horizontal surface adjacent to the haunching, shall be protected by about $2\frac{1}{2}$ inches of 1 : 3 : 5 concrete, reinforced with No. 8 or No. 10 wire cloth, electrically welded.

Every care shall be taken to insure satisfactory and thoroughly watertight joints between the main layer of waterproofing and the girders; and special attention shall be given to stiffeners, gussets, etc. The waterproofing shall also be carried down over the back walls to below the elevation of the bridge seat, or as directed.

Rolls of felt shall be stored on end, and not laid on their sides.

Waterproofing shall be done only by experienced and expert waterproofers.

Application of Waterproofing. Wherever called for, the decks of bridges shall be waterproofed with natural rock asphalt mastic, as specified below.

The concrete, prepared as specified heretofore, shall be waterproofed with asphalt mastic equal in quality, as to ingredients used and resistance to water, to the following specifications:

Sicilian rock asphalt mastic	60 parts
Clean, sharp, graded grit and sand to pass a sieve of 8 meshes per inch	30 parts
Asphalt as specified above for membrane binder	10 parts

These proportions shall be varied when required by special conditions on the work.

The mixture shall be made at the site of the work, shall be heated to a temperature of from 250 to 300 deg. Fahr. (121 to 149 deg. Cent.) and shall be stirred until all the ingredients are thoroughly incorporated. It shall then be spread and thoroughly worked, to free

it from voids, and shall be ironed to a smooth surface with smoothing irons, if so directed. All mastic shall be applied in two coats, making the required thickness. The two coats shall break joints, and the mastic shall be distributed evenly. Where the thickness of the concrete plus mastic is less than $2\frac{1}{4}$ inches, the full thickness shall be made up of asphalt mastic.

Pockets of asphalt shall be placed against all metal, and mastic along girders, around stiffeners, gussets, etc., as specified above.

Great care shall be taken around expansion joints, drain-pipes, and similar places, where a separation may take place.

After the mastic is laid, it shall be mopped with pure melted asphalt, and the surface shall be spread with a layer of clean, coarse sand, to harden the top.

The pockets of asphalt placed against the girders, stiffeners and gussets shall be protected by about $2\frac{1}{2}$ inches of 1 : 3 : 5 concrete, reinforced with No. 8 or No. 10 wire cloth, electrically welded.

The furnishing and erection of the steelwork for the bridge to be waterproofed will be executed under a separate contract, and the riveting will be completed, the erection finished, and the steel floor cleaned up ready for the waterproofing, before the work on this contract is begun. In addition to the foregoing, the contractor shall make a final cleaning of the steelwork before the work of waterproofing is begun.

Specifications for Waterproofing Station and Platform Floors of Railroad Viaducts by the Sheet-mastic Method. Where an asphalt floor is called for on mezzanines or station platforms, it shall be laid on 2-inch, tongue and grooved, yellow pine, the maximum width of the board being 6 inches. This board surface shall not be mopped with asphalt, but shall be covered with a layer of one-ply building paper or untreated felt. Where the asphalt floor is laid on concrete, the dry-ply shall be omitted, and a mopping of asphalt substituted.

The surface mixture shall consist of the following proportions by weight: Eleven and one-half ($11\frac{1}{2}$) parts of asphalt, ten and one-half ($10\frac{1}{2}$) parts of sand, thirty (30) parts of grit, forty-four (44) parts of limestone dust, and four (4) parts of Portland cement.

The sand shall be clean, sharp, and free from dirt, mica and vegetable matter. It shall contain both coarse and fine particles and shall be graded according to the percentages herein specified. Sand which does not fulfill the above requirements in its natural condition shall be screened, washed, or mixed with other sand to produce a result in accordance with said requirements. Of the ten- and one-half ($10\frac{1}{2}$) parts of sand, 100 per cent shall pass through a

ten-mesh sieve; 40 per cent shall pass through a forty-mesh sieve, 10 per cent shall pass through an eighty-mesh sieve.

All the grit shall pass through a four-mesh sieve, 30 per cent through an eight-mesh sieve, and 100 per cent shall be retained on a sixteen-mesh sieve.

All limestone dust shall be of such fineness that it shall leave a residue of not more than 20 per cent on a hundred-mesh sieve, and not more than 90 per cent on a two hundred-mesh sieve.

The fineness of the Portland cement shall be such that it shall leave, by weight, a residue of not more than 8 per cent on a hundred-mesh sieve, and not more than 25 per cent on a two hundred-mesh sieve; the wires of the sieves being respectively .0045 and .0024 inch in diameter.

All proportions herein mentioned are by weight.

The asphalt shall conform to the requirements (given in the specifications for "Waterproofing Subways by the Membrane System," page 281), except that when 20 grams of the material are heated for five hours at a temperature of 325 deg. Fahr. (163 deg. Cent.) in an electric oven, the loss in weight shall be not more than 1 per cent and the penetration shall be between .30 and .50 cm. at 77 deg. Fahr. (25 deg. Cent).

The asphalt floor mixture shall be made in an approved mechanical mixer or by hand in open fire-heated kettles. When made by machine, the ingredients should be weighed out and put into the mixer which shall cook and mix the mastic until it is of uniform consistency and temperature. Pre-heating of ingredients is dependent on the type of machine used, and shall be resorted to as directed by the engineer. At the end of each day's work, the mixer shall be thoroughly cleaned. All materials used in making mastic should not be unduly exposed to the weather. The mastic shall be brought to the place of application in wooden pails properly covered so as to retain the heat. The temperature of the mastic in the mixer should not exceed 400 deg. Fahr. (204 deg. Cent.) and it should not be less than 300 deg. Fahr. (149 deg. Cent.) at the time of application.

When the mastic is made by hand, the sand, grit, limestone dust, cement and asphalt shall be heated to approximately 325 deg. Fahr., the asphalt being heated separately. The maximum temperature of the sand, grit and limestone dust, as delivered at the mixing kettle, shall not exceed 375 deg. Fahr. (191 deg. Cent.) and the maximum temperature of the asphalt shall not exceed 350 deg. Fahr. (177 deg. Cent.).

The Portland cement shall be thoroughly mixed dry with the

sand, grit and limestone dust. This mixture shall then be sprinkled into the hot and molten asphalt until a homogeneous mixture is produced, in which all particles are thoroughly coated with asphalt.

The mastic shall be prepared on or close to the work and in amounts not exceeding that quantity which can be laid in one working day. The maximum temperature of any batch of mastic immediately after being mixed shall not exceed 400 deg. Fahr. and the minimum temperature when delivered on the pine floor shall be not less than 300 deg. Fahr.

The mastic, containing materials which will become separated by subsidence while the asphalt is in a melted condition, shall be thoroughly agitated before being drawn and while in the supply kettles. Approved methods of agitation shall be used.

The contractor shall, at his own expense, provide a sufficient number of accurate, properly constructed thermometers for determining the temperatures of the mastic at all stages of the work.

After the mixture has been spread and compressed to a uniform thickness of one (1) inch, it shall be rubbed to a smooth surface with a wooden float. Expansion joints shall be provided where necessary.

Remarks. The above specifications are used by the Public Service Commission, 1st Dist., State of New York, on all new elevated work of the New York Dual Subway System. The clause calling for the board surface not to be mopped, but covered with a layer of building paper or untreated felt, is at variance with most similar specifications, but has been found necessary to avoid the formation of vapor bubbles on the finished mastic surface. The clause permitting the asphalt floor mastic to be made either in a mechanical mixer or by hand, is believed to be a good departure from former limitation to hand mixing.

Specifications for Waterproofing Concrete Floors. Thoroughly mix one-half each of *D* * and tested Portland cement by weight. They should be mixed (dry) until absolutely uniform in color and showing no streaks. Then set aside until ready for use.

Lay floor base and topping as usual. The topping should be at least $\frac{3}{4}$ inch thick and should be made of one part good tested Portland cement and two parts clean, sharp, coarse sand, free from loam and clay. See that the topping is not made too wet, then float well.

After the topping is laid and evened, as is usually done, powder or dust the floor with the *D* cement mixture, using 30 pounds of

* These specifications are for the use of a proprietary preparation of finely powdered iron, and designated by *D*.

mixture (15 pounds each of *D* and cement) to each 100 square feet of topping. Use a small flour sieve for sifting or distributing this mixture over the surface. Allow dust coat to stand about five minutes, then float mixture in well with wooden trowel and trowel hard.

When fairly set, showing no signs of surplus water on surface, trowel a second time until the topping has a smooth, hard finish.

After the floor is from twenty-four to forty-eight hours old, cover it evenly with an inch layer of wet pine sawdust or shavings, sand or bags and rewet same twice daily for four or five days. Do not apply the sawdust, etc., until the floor is thoroughly set, as same may adhere to and ruin the finish of the floor.

Do not use floor for seven days, or while it is curing. Under no circumstances should heavy trucking be done on a floor less than thirty days old. Cover the floor with boards to assure complete protection.

Specifications for Waterproofing Roofs

The Shingle (Tile) Method. The intention of this specification is to secure a watertight roof by the application of a waterproofing felt layer and an overlying covering of tiles. The roof, prior to the application of the roofing, shall have been constructed in strict accordance with the plans. The roof sheathing should be well laid and tight, all chimneys and walls above roof line completed, and all vent-pipes through the roof properly fastened.

The gutters shall be placed in position, extending over the roof sheathing (and cant strips, if same are used), and under the felt and tile at least 8 inches. All valley metal shall be in place, and the width of same must be 24 inches with both edges turned up $\frac{1}{4}$ inch for the entire length of the valley. This valley metal shall be laid over one layer of felt running the entire distance of the valley. All flashing metal used alongside and in front of dormers, gables, skylights, towers, perpendicular walls, also around vent-pipes and chimneys, shall be placed in accordance with the requirements of the tiles.

Upon the properly prepared roof, the sheathing shall be covered with one thickness of asphalt or pitch-treated roofing felt, weighing not less than 30 pounds per square. The felt should be laid with $2\frac{1}{2}$-inch laps, and fastened with capped nails. The felt shall be laid parallel with the eaves, and lapped about 4 inches over all valley metal. It shall also be laid under all flashing metal, and turned

up about 6 inches against all vertical walls. Upon this felt layer the tiles shall be fastened with copper nails. They shall be well locked together, lay smoothly, and no attempt shall be made to stretch the courses. The tile must be laid so that the vertical lines are parallel with each other, and at right angles to the eaves.

The tiles that verge along the hips shall be fitted close against the hip board, and a watertight joint made by cementing the cut hip tile to the hip board with a good elastic cement. Each piece of hip roll shall then be nailed to the hip board, and the hip rolls cemented where they lap each other. The interior spaces of the hip and ridge rolls must not be filled with pointing material.

The tiles shall be of the pattern known as (*brand of tile and name of manufacturer here mentioned*). The tile as specified above must be of shale, hard burned, and of (*insert color desired*) color. All hip and valley tile shall be cut to the proper angle before burning.

Remarks. The above specifications are applicable to pitched roofs only. It does not emphasize the importance of the felt layer underlying the tiles. The one defect of tile roofing is that it is subject to breakage, and when this happens almost sole dependence for continued watertightness (until the tile is replaced) is upon the felt. Therefore the felt should be applied with care, and be of the elastic, built-up, membrane type, that is, consist of at least two plies cemented and properly nailed down. The grade and hardness of the pitch or asphalt used as binder, must also be considered. A good feature is that it permits the selection and use of many patterns of tile.

Composition Roofing Method. (*A*) *Over Board Sheathing.**
Lay one (1) thickness of sheathing paper or unsaturated felt weighing not less than five (5) pounds per one hundred (100) square feet, lapping the sheets at least one (1) inch. See Fig. 113.

Over the entire surface lay two (2) plies of tarred felt, lapping each sheet seventeen (17) inches over preceding one, and nail as often as is necessary to hold in place until remaining felt is laid.

Coat the entire surface uniformly with coal-tar pitch.

Over the entire surface lay three (3) plies of tarred felt, lapping each sheet twenty-two (22) inches over preceding one, mopping with coal-tar pitch the full twenty-two (22) inches on each sheet, so that in no place shall felt touch felt. Such nailing as is necessary shall be done so that all nails will be covered by not less than two (2) plies of felt.

* This specification should not be used where roof incline exceeds three (3) inches to one (1) foot.

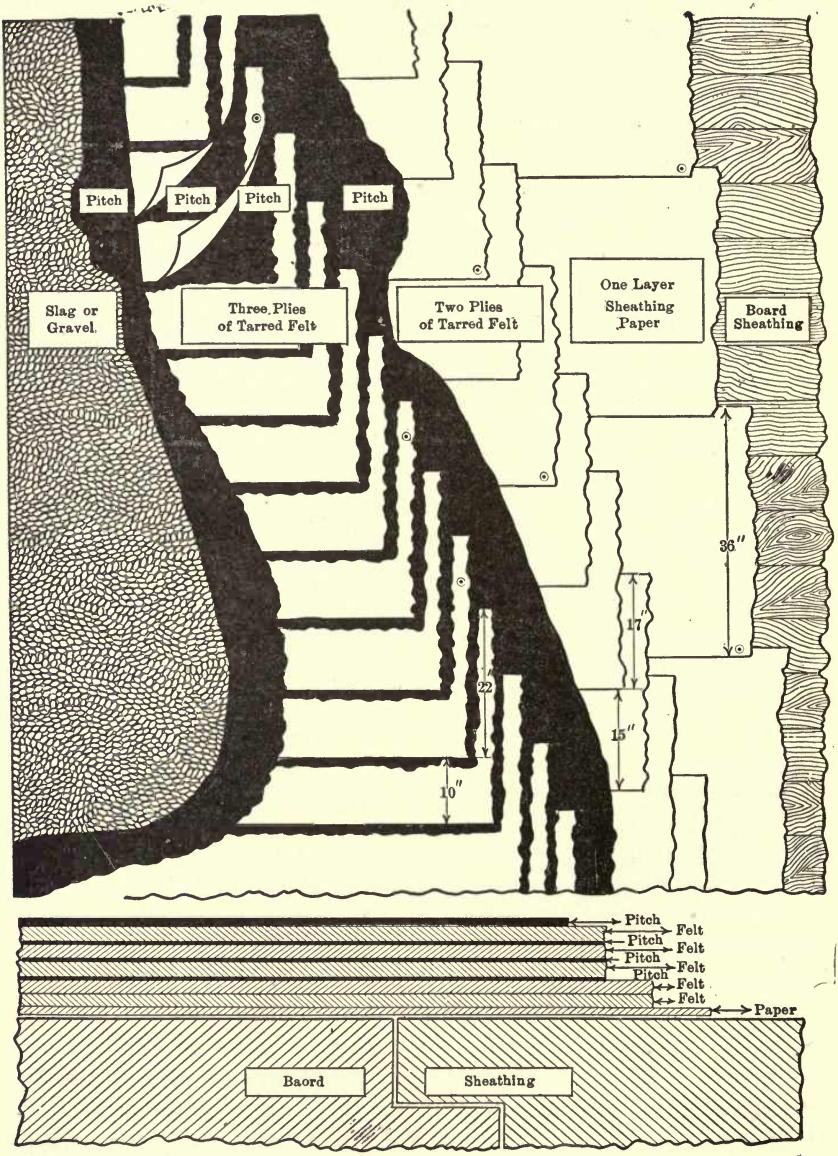


FIG. 113.—Details of Built-up Slag Roof over Board Sheathing.

Spread over the entire surface a uniform coating of pitch, into which, while hot, embed not less than four hundred (400) pounds of gravel or three hundred (300) pounds of slag to each one hundred (100) square feet. The gravel or slag shall be from one-quarter ($\frac{1}{4}$) to five-eighths ($\frac{5}{8}$) inch in size, dry and free from dirt.

The roof may be inspected before the gravel or slag is applied by cutting a slit not less than three (3) feet long at right angles to the way the felt is laid. All felt and pitch shall bear the manufacturer's label.

(*B*) *Over Concrete.** 1. Coat the concrete uniformly with hot pitch, see Fig. 114.

2. Over the entire surface lay two (2) plies of tarred felt, lapping each sheet seventeen (17) inches over preceding one, mopping with coal-tar pitch the full seventeen (17) inches on each sheet, so that in no place shall felt touch felt.

3. Coat the entire surface uniformly with pitch.

4 and 5. Same as for waterproofing roofs over board sheathing.

Remarks. The above specifications are equally applicable to roofs waterproofed with asphalt-treated felt and asphalt binder. For best result, with built-up roofings, both the coal-tar pitch and the asphalt must be carefully selected, as other than the best grades of these materials are very vulnerable to the weather.

The Tin Roofing Method.† All of the tin used for roofing all parts of a building shall be tinned iron sheets, which shall be stamped with the brand and thickness on each sheet.

All tin used for standing seam roofing shall be IC‡ thickness, 14 by 20 inches, applied with the 14-inch face parallel to the eaves, forming seams with a double lock. All tin for standing seam roofing shall be put together in rolls with the cross seams formed and soldered, same as specified for flat seam roofing.

All standing seam roofing shall be fastened to roof with 2-inch wide tin cleats, spaced 8 inches apart, with cleats locked into seams, and each cleat fastened with two 1-inch barbed wire nails.

All tin used for flat roofing shall be IC thickness, 14 by 20 inch size, using flat seams, with $\frac{3}{8}$-inch lock. Flat seam roofing should

* This specification should not be used where roof incline exceeds three (3) inches to one (1) foot, and when incline exceeds one (1) inch to one (1) foot, the concrete must permit of nailing or nailing strips must be provided.

† Richey's "Building Mechanics' Ready Reference."

‡ Plates are made in two weights, IC and IX. The IC is No. 30 gauge, and weighs 0.5 pound to the square foot. The IX is No. 28 gauge, and weighs 0.625 pound per square foot. Either grade is suitable for either flat or standing seam roofing.

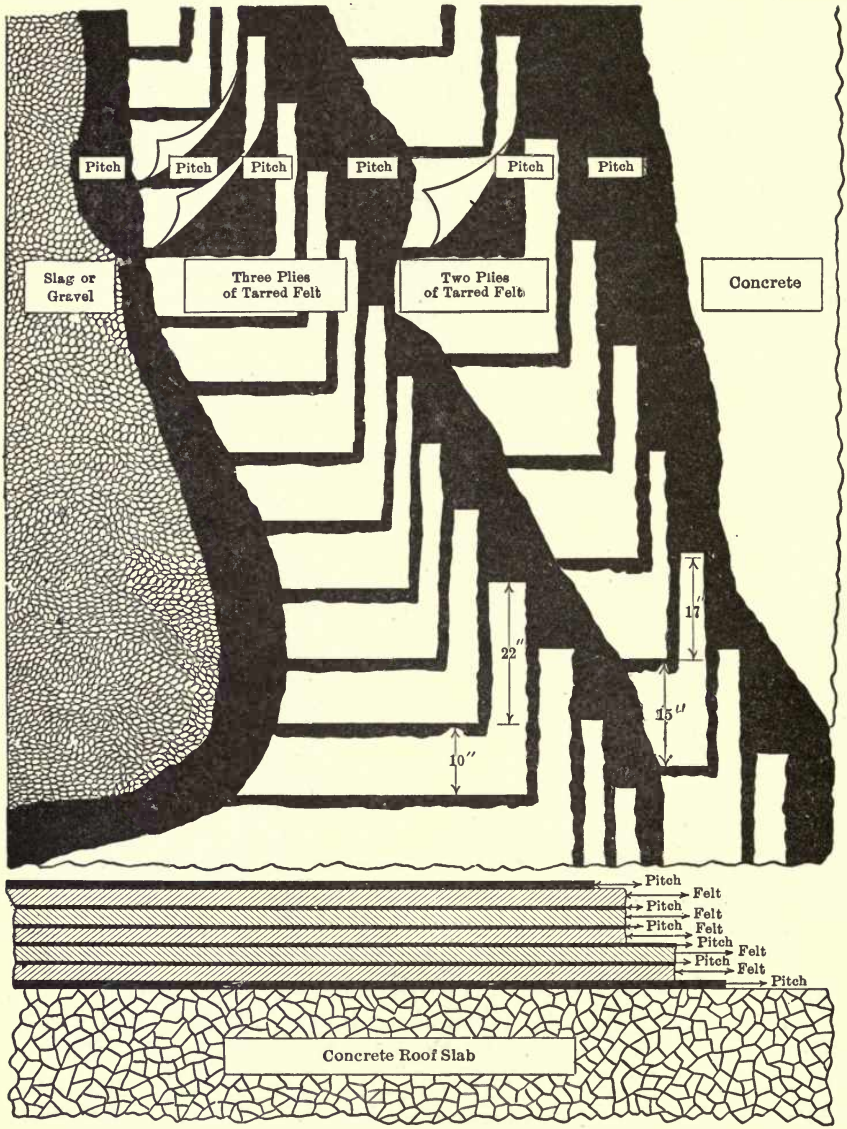


FIG. 114.—Details of Built-up Slag Roof over Concrete Slab.

be made up and soldered in the shop in long lengths, which must be painted on under side with one coat of paint and allowed to dry before applying to the roof. All flat-seam roofing shall be fastened to roof with 2-inch wide flat tin cleats, spaced 8 inches apart, with cleats locked into seams, and each cleat nailed to roof with two 1-inch barbed wire nails. When the rolls of tin are laid on roof the edges shall be turned up ½ inch at right angles to roof, when the cleats shall be installed. Then another course shall be applied with ½-inch upturned edge, the adjoining edges shall be locked together, and the seam so formed shall be flattened to a rounded edge and well soldered and soaked in.

All valleys shall be formed with flat seam roofing, using 14 by 20 inch sheets laid in the narrow way, with cross seams put together and well soldered, same as specified for flat roofing.

All flat seams throughout the roof, including such other parts as may need soldering to make perfectly watertight, shall be soldered with best grade of guaranteed half-and-half solder (half tin and half lead), using nothing but rosin as a flux. Not less than 2 pounds of solder shall be used per square on standing seam roofing, and not less than 8 pounds per square on flat seam roofing, all to be well sweated into the joints.

All rosin used in soldering must be carefully cleaned off from all surfaces before any paint is applied to the tin.

All tin shall be painted one coat on concealed or under side, as heretofore specified, and two coats on all exposed surfaces: the first coat shall be given four weeks to dry before the second coat is applied. All paint shall be applied with hand brushes and well rubbed in. Litharge only shall be used as a drier. No patent drier or turpentine is to be used. The first coat on upper surface shall be applied as soon as laid, and the tin must not be permitted to rust before painting.

Specification for Waterproofing Railroad Station Roof.* All roofs in connection with the station buildings shall be made absolutely watertight and weatherproof with (*name of manufacturer*) " Built-up Asbestos Roofing " or equal thereto.

The asphalt shall be (*name of brand*) or equal thereto and shall be applied sufficiently hot to flow freely.

The felt shall be asphalt-saturated asbestos felt (*name of brand*) or equal thereto.

The parapet walls, plumbing pipes, smoke pipes, etc., to a height of not less than 4 inches, the lower edge of the main roofs and all

* New York Municipal Railway Corporation, Brooklyn, N. Y.

roofs at the walls and pipes to a width of not less than 12 inches shall be thoroughly mopped with asphalt and therein, while it is still hot, shall be embedded one thickness of felt to which a second thickness of felt shall be thoroughly wiped with hot asphalt. The two thicknesses shall be not less than 4 inches high on the walls and pipes nor less than 12 inches wide on the roofs and shall be applied before the flashings and roof boxes are set in place.

After the copper flashings and roof boxes have been set and the leaders connected, the surface of the roofs shall be covered with not less than three thicknesses of felt laid $10\frac{1}{2}$ inches to the weather, thoroughly embedded and wiped down in hot asphalt and well wiped to the flashings and leader boxes, the felt to be rolled close behind the mop so that no missing of hot asphalt can possibly take place.

The entire surface shall be finished to a smooth, even surface with a heavy coat of (*name of manufacturer*) "Asphalt Roof Coating" or equal thereto.

All flashings and cap flashings in any way required to make the entire work absolutely weathertight shall be furnished as a part of the work under this section.

The flashings, cap flashings, and roof boxes shall be made of 16-ounce cold rolled copper except the flashings and cap flashings to the smoke pipes which shall be 20-ounce cold rolled copper.

The mason shall be furnished the cap flashings to be built into the concrete; these are to be 8 inches wide and built 2 inches into the concrete with the built-in edge turned up $\frac{1}{2}$ inch; they are to be set not less than 8 inches above the roof and where stepped should be lapped not less than the height of the step.

The flashings shall be turned 4 inches under the roofing and shall be of sufficient width to fit closely under the built-in portion of the cap flashings; they are to be set after two layers of roofing have been applied as hereinbefore specified, and the cap flashings are to be bent down and heavily tinned and soldered at all corners and angles.

All soldering in any way required to make the entire work absolutely watertight and weatherproof, shall be done in the neatest and best manner. The copper which is to be soldered shall be heavily tinned and all joints shall be thoroughly sweated and neatly soldered over and all superfluous solder shall be neatly removed.

All sheet metal work and roofing shall be delivered at the final completion of the works, clean, whole, perfect, and absolutely watertight and waterproof.

CHAPTER IX

PRACTICAL RECIPES AND SPECIAL FORMULAS

Origin and Nature of Special Formulas

Considering the many varied purposes and conditions under which the different systems of waterproofing are found serviceable, it is surprising how few are the basic waterproofing compounds in common use. Not more than fifty of such compounds are in the market. Of these compounds the integral system claims about 30 per cent, the surface coating system about 40 per cent, and the membrane and mastic systems about 30 per cent. The grouting and self-densified processes are not considered in this connection because they require, besides a good grade of material, only scientific manipulation for successful work. The general nature of most of the basic compounds is discussed in Chapter V. On the other hand, of the special waterproofing compounds there are at least several hundred. The nature of these, of course, is in most instances kept as a trade secret. Still, from time to time, some chemists and engineers discover or invent useful waterproofing compounds or new processes for utilizing old compounds. These are often published in the technical press of both the chemical and engineering professions. Government chemists, and engineers in particular, are very resourceful and liberal in this regard. The United States Department of Agriculture, the Department of Interior and the Department of Commerce and Labor, publish annually scores of bulletins and technical papers some of which are replete with valuable information, suggestions, and tests on new and old waterproofing methods and materials,* which are often distributed free and never for more than cost. These publications are regarded with great favor and authority in the waterproofing industry; and well they may be, for they are always unbiased, truthful and practical, the only adverse criticism

* As illustrations of the types of these papers, see Bulletin No. 230 of the Office of Public Roads, U. S. Department of Agriculture; Technologic Paper No. 3 of the Bureau of Standards, Department of Commerce and Labor; Bulletin No. 329 of the U. S. Geological Survey, Department of Interior.

being occasioned, in a few instances, by the occasional incompleteness of the data and the results based thereon.

Waterproofing formulas, like paint formulas, are often individual secrets, kept by the discoverer from the world for his commercial advantage. Like most paints, waterproofing compounds, unless investigated by the most competent chemists, often baffle chemical analysis, and more often chemical synthesis. The method of combining, or the process of manufacturing most waterproofing compounds, is more difficult and kept more secretive than is the knowledge of the constituent ingredients. Of course, where compounds are patented, a certain amount of information is divulged to the public, but the patent prevents the unlicensed use of the compounds. This facilitates and sometimes encourages the marketing of imitations, better or worse, which the purchaser must guard against by careful investigation.

In compiling this chapter the author has freely availed himself of all the above-mentioned sources with due acknowledgment. Included also are formulas and practical recipes derived from personal experience and the experience of a few associates in both the chemical and engineering professions. In making compounds from any of these formulas, care and judgment are essential to success. They are arranged under the general heads of Masonry Treatments, Treatments for Tanks, Floor Treatments, Roofings, and Waterproof Cements, but no strict divisions were attempted.

Masonry Treatments

Waterproof Mortar. For masonry joints: equal parts of sand and cement with sufficient water to form a plastic paste produces a very waterproof mortar; for surfacing and stucco work a 1 : 2 mortar is very efficient provided it is allowed to dry very slowly. A mixture consisting of one-sixth underburnt and one-sixth well-burnt powdered brick, one-third slaked lime, and one-third sand, will make a dense, waterproof mortar.

Dampproof Coating Compounds for Masonry. An easily made and applied coating for dampproofing purposes consists of about 20 per cent, by weight, of paraffin (melting-point between 104 and 122 deg. Fahr. (40 and 50 deg. Cent.) dissolved in 80 per cent of a petroleum oil mixture. This mixture may be made of about 45 per cent benzene, 25 per cent wood turpentine and 30 per cent kerosene.

A similar compound can be made by mixing about 5 per cent, by weight, of paraffin, 5 per cent alumina resinate, 45 per cent benzine and 45 per cent kerosene.

A good surface-coating compound can be made in the form of a thin paste by mixing with water to the required consistency, about 96 per cent by weight of powdered cast iron and 4 per cent of sal-ammoniac. This paste should be carefully applied, preferably in two coats with a stiff brush, as it is necessary for it to adhere to the concrete to be effective.

A solution of water glass (about 5 per cent) when applied as a coating to a surface containing lime will form a hard, impervious finish by the chemical action between the lime and the alkaline silicate or water glass. On concrete it is rather difficult to accomplish this action because the lime is not free to get at.

Surface Coatings for Masonry. A liquid, waterproof, surface coating, consists of the following formula: 70 per cent of asphalt, 30 per cent of turpentine substitute or other petroleum product. The petroleum product should be added while the asphalt is hot. The mixture can then be applied cold with a brush. It may also be mixed as an integral compound in mass concrete or mortar in quantities ranging between 5 and 10 per cent by weight of cement.

A plastic form of waterproof surface coating may be made as follows: Pine creosote oil, about 40 per cent; fiber asbestos, 30 per cent; pine pitch 30 per cent. The pitch and oil must be cooked together and the asbestos added while the mixture is hot. This material is viscous enough to be troweled on the masonry and can be applied to a wet or dry surface.

A durable, tough, and elastic compound that can be used for both roof coverings and flashings consists of a good grade of refined asphalt mixed with from 5 to 25 per cent of stearine pitch. The proportion is governed by the consistency desired and the melting-point of the asphalt.

The following surface coating will remain plastic and elastic for a long time. It is applied cold, by troweling on the surface to be waterproofed. Hot elaterite, about 85 per cent; mixed with about 15 per cent of castor oil or cotton-seed oil. If a little gutta percha is added, the compound is considerably improved.

An impervious surface coating for industrial concrete wash basins, etc., can be obtained by rubbing the inside surface with a cement brick just after removing the forms. This brick can be made of a 1 : 2 mortar. While rubbing, the concrete surface should be sprinkled constantly with water; this will form a paste over the surface and

tend to fill the pores. Two or three rubbings in this manner will produce a very impervious surface.

Dampproofing for Brick Walls.* In applying the following compounds all dampness of the wall must first be allowed to dry up as much as possible. The process of dampproofing then proceeds as follows: One coat of boiled linseed oil is first applied over the wall and all joints. All holes are then puttied up with a paste composed of pure linseed oil and whiting, colored with fine brick dust or Venetian red. Venetian red, thinned with equal parts of boiled linseed oil and turpentine, is then applied as a second coat. Finally a third coat of red oxide and drier is applied as a finish coat. The color may be changed from a red to any desirable tint using white lead as the base, tinting with oil color to suit.

Another formula is as follows: Venetian red mixed with skim milk (casein). The action of the lime base in the Venetian red will make the curd of the milk insoluble in water. Should the Venetian red be free from lime, then lime water, whiting or quick lime must be added to the milk before mixing the Venetian red with it. (To ascertain whether the Venetian red contains whiting or lime, a portion of it is dropped in some commercial sulphuric acid, and if the red powder does not effervesce, lime in the form needed is not present, and the aforesaid alkaline addition must be made.) If the color is to be waterproofed, however, to each gallon thereof must be added one-half gallon boiled linseed oil and well stirred. Both these mixtures, when properly made, will not wash off for years.

A water-shedding, dampproofing compound for brick and concrete masonry may be made by mixing about 80 per cent of kerosene with 10 per cent of acetone and 10 per cent of creosote. This compound should be applied with a brush and thoroughly rubbed in on a clean surface. It tends to fill the pores of the masonry and shed water from the surface.

A damp-resisting paint can be made by mixing, until solution is effected, melted Manila or Copal gum with linesed oil or China wood oil; this mixture is then dissolved in benzol or naphtha. It is applied with a brush in several coats. For a top coat it is well to evaporate more of the gum and add more of the drying oil. The compound may also be mixed with any desired pigment.

Stone Preserving Compositions.† With the following liquid compound it is possible to preserve a brownstone front against the

* "739 Paint Questions Answered," published by The Painters' Magazine of New York in 1904.

† "Scientific American Cyclopedia of Formulas," 1915.

weather without altering its appearance, its stony aspect not being altered by the liquid after it has penetrated and dried. Ten gallons of thinning liquid, such as fish oil, or linseed oil, mixed with 2 pounds dry zinc white, and 5 pounds powdered brown oxide. Before applying the liquid, the surfaces should be brushed clean with wire brushes.

Paraffin is the best material for rendering natural stones, concrete and brick-work impervious to water. If dissolved in the proportion of one-third paraffin and two-thirds kerosene, it remains soft longer and penetrates the stone further. Paraffin is unaltered by weather or acids. If carefully melted in, it does not change the color of the stone; it simply deepens the color like water. It is cheap, easily applied and efficacious. It is most easily applied in hot weather.

Leaks in concrete walls can be stopped by enlarging the cracks and applying a hot mixture of Portland cement and caustic soda, which sets almost instantly. The concrete around the leak should be cut out so that the hole or groove is larger at the base than at the surface. The hot paste is then applied rapidly with gloved hands, first against one side of the cavity and then successively around the sides of the cavity until it is completely closed. The soda should be mixed with little water and be boiling hot when the cement is added in amounts enough to make a stiff paste.*

Treatment for Tanks

Preserving Concrete Tanks from Commercial Liquids.† The following fluids may be stored in tanks made of plain dense concrete of 1 : 2 : 4 mix without causing any deterioration in the concrete: Menhaden oil, linseed oil, rosin oil, 4 per cent caustic soda solution, tanning solution, and sauerkraut.

For safely storing sulphite liquor and cider vinegar in concrete tanks, the only satisfactory method found to protect the concrete from disintegration is by applying a surface coat of an oil-gilsonite compound. This compound is made by dissolving 100 parts, by weight, of gilsonite in 250 parts of turpentine, and adding 5 parts of neutral petroleum oil. At ordinary temperatures, with frequent stirring, about twenty-four hours will be required for a perfect

* Engineering Record, March 3, 1917.

† Results of a series of tests, extending over a period of more than a year, made for the Portland Cement Association to determine the effects of commercial liquids on concrete tanks, by the Institute of Industrial Research, Washington, D. C. Reported in Engineering Record, Vol. 74, No. 16, October 14, 1916.

solution. Two coats of this mixture should be applied with a brush to the inner surface allowing at least twenty-four hours for each to dry.

For safely storing molasses in concrete tanks, in a manner so that neither the molasses nor the concrete is injured, the inner surface should be well protected with two coats of Bakelite varnish. Concentrated brines may similarly be stored in concrete tanks by coating the inside with two layers of the above-mentioned oil-gilsonite compound between which is placed an asphalt-treated fabric. Upon this one-ply membrane should be placed a 1 : 2 cement mortar coating, and the latter painted with two coats of Bakelite.

Cement to Resist Benzine and Petroleum.* Gelatine mixed with glycerine yields a liquid compound when hot, but which solidifies on cooling, and forms a tough, elastic substance, having much the appearance and characteristics of India rubber. The two substances unite to form a mixture absolutely insoluble in petroleum or benzine, and the problem of making casks impervious to these fluids may be solved by brushing or painting them on the inside with this compound. Water must not be used with this compound.

Wooden and Iron Tanks Made Watertight. Wooden tanks should first be drained well and permitted to dry out thoroughly. Then the hoops must be tightened and the inside be given a coat or two of hot paraffin oil or melted paraffin wax, applied while hot. This done, the iron or steel hoops should receive a coat of red lead and the outside of the tank one or two coats of good, elastic oil paint of any color desired.†

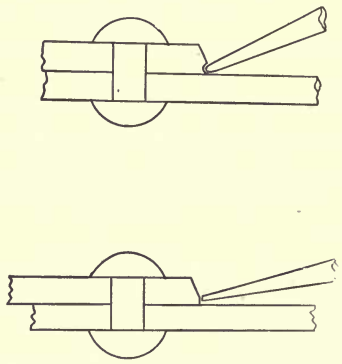


FIG. 115.—Calking Operation with Hand or Pneumatic Calking Tools.

Joints in iron tanks that have opened up can be sealed effectively by calking with proper tools (see Fig. 115). This operation consists in beating down the edges of the metal against the face of the opposite plate. The round-nosed calking tool is usually employed in modern practice. A more effective way of calking is with lead wool hammered

* "Scientific American Cyclopedia of Formulas," 1915.

† "739 Paint Questions Answered," published by The Painters' Magazine of New York in 1904.

into the joint. Coating the outside of the joint with a thick application of a hard, tough asphalt or a sealing wax of a similar nature, is also effective except for hot-water tanks. Both of these materials must be applied on a properly cleaned surface.

A preserving varnish for wood and metal tanks is easily made by mixing three parts of pure asphalt (solid or liquid variety) with four parts of boiled linseed oil and from fifteen to eighteen parts of turpentine.

Floor Treatments

Concrete Floor Hardener. The following formula is used for hardening concrete floors: Powdered pig iron mixed with about 2 per cent, by weight, of salammoniac. This mixture may be floated on a partially set concrete surface which is thereby hardened for a depth of a fraction of an inch, but it is not very durable. The mixture may also be combined with Portland cement in equal proportions by weight to form a mortar that is applied, about $\frac{3}{4}$ inch thick on a clean surface of concrete. This mortar coat will create a dense and impervious floor if properly and carefully applied. A serious objection to the use of this formula is the frequent discoloration of the surfaces treated due to the uneven distribution and oxidation of the powdered metal.

Wooden Floor and Flooring Made Watertight.* Flooring may be made impermeable by being painted with a solution of paraffin wax dissolved in kerosene. The coat will last for about two years.

Roofings

Roofing Paper.† Old newspapers or sheets of wrapping paper in good condition may be converted into waterproof roofing material by coating them with hot coal-tar pitch or asphalt with a brush, and uniting two or more sheets. These mats can then be applied to a roof, shingle fashion, creating a cheap but good roofing for sheds and shanties and for temporary, small constructions.

Roofing Cement. A waterproof bituminous cement for binding roofing felt, one that will not flow readily in the summer's heat, may be made by mixing one part of burnt lime (but not slaked) with seven parts of coal tar, both by weight. The lime is powdered

* "Scientific American Cyclopedia of Formulas," 1915.

† "Scientific American Cyclopedia of Formulas," 1915.

and sprinkled into the hot tar, with which it mixes intimately. The mixture hardens on cooling and therefore must be applied hot.

Waterproof Cements

Adhesives. The following waterproof cements can be made with but little difficulty or previous experience:*

(1) Shellac, 4 ounces; broax, 1 ounce; boiled in a little water until dissolved, and concentrated by heat to a paste.

(2) Carbon bisulphide, 10 parts; oil of turpentine, 1 part; mixed with as much gutta-percha as will readily dissolve in the mixture.

(3) Tar, 1 part; tallow, 1 part; fine brick dust, 1 part; the latter should first be warmed over a very gentle fire; the tallow added, then the tar, and the whole thoroughly mixed. This compound must be applied while hot.

(4) Good quality gray clay, 4 parts; black oxide of manganese, 6 parts; lime, reduced to powder by sprinkling with water, 90 parts; the combination mixed, calcined and powdered.

(5) A very strong cement, but one which requires to be applied directly after being made as it sets very quickly, is the following: Quicklime, 5 parts; fresh cheese, 6 parts; water, 1 part. The lime is slaked by sprinkling with water; thereupon it is passed through a sieve, and the fresh cheese is added. The latter is prepared by curdling milk with a little vinegar and removing the whey.

(6) A cement adapted for joining stone, metal, wood, etc., can be made as follows: Fresh curd, as before, 1 part; Roman (natural) cement, 3 parts. This must be well mixed and quickly applied.

(7) A cementing paste composed of hydraulic lime and dissolved water glass will withstand the action of heat as well as water.

(8) Glue, 1 part; black rosin, 1 part; red ochre, $\frac{1}{4}$ part; mixed with the least possible quantity of water.

(9) Glue, 4 parts; boiled linseed oil, 1 part; oxide of iron, 1 part all by weight and well mixed together.

(10) A good cement is made by mixing about 7 parts of litharge and 93 parts of burned clay or whiting together reduced to a fine powder and made into a paste with linseed oil.

† (11) A cement may be formed by mixing into a paste freshly calcined oyster shell lime, well sifted and ground fine with white of egg.

* "Scientific American Cyclopedia of Formulas," 1915.

† "739 Painters Questions Answered," Painters' Magazine, New York.

(12) Four parts, by weight, of shellac boiled with 1 part, by weight, of borax in water until the shellac is dissolved. This mixture should be kept boiling until it is of a paste-like consistency. To use this paste it must be heated and applied with a clean brush.

(13) For many odd and varied purposes, commercial sealing wax will prove a very good waterproof cement. It consists of hard resinous materials, such as lac, with some form of pigment, as vermilion. Beeswax alone or mixed with a fine mineral dust can also be used to advantage.

Waterproof Cement for Leather.* A waterproof cement for leather is prepared by dissolving gutta-percha, caoutchouc, benzoin, shellac, mastic † and similar materials, in some convenient solvent like carbon disulphide, chloroform, ether or alcohol. The best solvent, however, in the case of gutta-percha is carbon disulphide, and ether for mastic. The most favorable proportions are as follows: Gutta-percha 200 to 300 parts to 100 parts of the solvent, and 75 to 85 parts of mastic to 100 parts of ether. From 5 to 8 parts of the former solution mixed with 1 part of the latter and boiled in a water bath to any consistency desired makes a good cement.

Waterproof Compounds for Textile Fabrics.‡ Textile fabrics can be made waterproof by successive impregnations with a solution of soap and a solution of alum. Or, by successive impregnations with a solution of alumina sulphate (made by dissolving in ten times its weight of water), and a soap solution composed of 1 ounce light-colored rosin, 1 ounce of crystallized soda, boiled together in 10 ounces of water until dissolved. Also by impregnation, first with a solution of ammoniacal cupric sulphate of 10 deg. Baumé at 77 deg. Fahr. (25 deg. Cent.) then, with a solution of caustic soda of 20 deg. Baumé. Increased impermeability will be obtained by using sulphate alumina in place of caustic soda. To waterproof one side of cloth, it must be imbued on the wrong side with a solution of isinglass, alum, and soap in equal parts each dissolved separately, and made into a solution with sufficient water. Another method is to impregnate the fabric with hot, molten paraffin.

Sheets of canvas or tarpaulins may be made waterproof by painting the surfaces with or dipping them in a mixture of coal tar, gasoline and a good Japan drier in the proportion of 5 : 1 : 1.

* "The Manufacture of Varnishes and Kindred Industries," by Livache and McIntosh, Vol. 3, p. 376.

† A form of resin secreted by shrubby trees cultivated on the island of Chios in the Greek Archipelago.

‡ "Scientific American Cyclopedia of Formulas," 1915, Munn & Co., Inc.

Waterproof Compound for Drawing and Tracing Sheets.* Drawing and tracing sheets can be made waterproof, so that they may be used in wet places, as in mines, for instance, by the application, to one or both sides, of a preparation composed of rubber and benzol. The preparation is made by dissolving a quantity of pure rubber in benzol and thinning down with more benzol to any desired consistency. The rubber first swells enormously and in about twenty-four hours is ready for use. For use as a waterproof adhesive the solution should be fairly stiff. Only the pure gum rubber is satisfactory for this purpose.

* Engineering News-Record, Vol. 81, No. 13, September 26, 1918, p. 597.

CHAPTER X

WATERPROOFING APPLIED

WATERPROOFING applied forms an important part of waterproofing engineering and also a very interesting one. It describes accomplishment in the field. Chemical analyses and physical tests of waterproofing materials are important but they are, after all, mostly accelerated tests. Service is the real " acid test " for all waterproofing materials and their application. The best criterion of the relative merits of the various materials and systems of waterproofing discussed in previous chapters is their efficacy and endurance in service. Many secret and patented compounds and various types of waterproofing cannot be fairly judged in any other way than by their past performences. In fact, certain grades of asphalt have won favor and preferance for waterproofing purposes by no other means than past service. Coal-tar pitch is extensively used for waterproofing underground structures for the same reason. On the other hand, many integral and surface-coating compounds proved their unworth in this manner though apparently successful in the laboratory. The grouting process of waterproofing is advancing rapidly now only because of its efficiency as proved in service.

In this chapter will be found practical instances of each of the six systems of waterproofing previously discussed; also the standard and special materials used, the methods of application and where possible the degree of success obtained.

EXAMPLES OF SURFACE COATING APPLICATIONS

Water Storage Works, U. S. Reclamation Service. The storage works and tunnel connected with the Strawberry Valley Project * in the U. S. Reclamation Service are located in the Wasatch Mountains at an elevation of 7500 feet, surrounded by mountains, some of which reach an elevation of 10,000 feet above sea level. There is a wide variation in temperature in this vicinity during the entire

* Enginerring News, Vol. 73, No. 15, April, 1915.

year, and the climate is very severe during the winter months, the lowest temperature on record being 50 deg. Fahr. below zero. The snowfall ranges from 10 feet in low years to 24 feet in high years. On account of these conditions of extreme cold, with alternate thawing and freezing, the action of water and frost on concrete that is not impervious is very marked. It was therefore decided to treat the concrete with some sort of preventive against absorption of water by the surfaces exposed.

A study was made of the various waterproofing processes in common practice. Because the structures had been completed, and in view of the extraordinary conditions, it was decided to treat the vertical surfaces with alum and soap solutions (Sylvester process) and the horizontal ones with paraffin.

The alum solution was made by dissolving 2 ounces of alum in 1 gallon of hot water. The soap solution was composed of $\frac{3}{4}$ pound of castile soap dissolved in 1 gallon of hot water. The paraffin was boiled to rid it of any water content, as the presence of water rendered it hard to apply. Ordinary commercial products were used.

The surface to be treated with paraffin was first entirely freed from all moisture, loose concrete, dirt and other foreign substances. The paraffin was then heated and applied to the surface of the concrete with a paint brush and was forced into the pores by flashing the flame of a blow torch over the surface.

In the application of the alum and soap (which produces an insoluble aluminum stearate in the pores and on the surface of the concrete), the surface of the concrete was first prepared in the same manner as for the paraffin treatment. The alum solution was then applied at a temperature of 100 deg. Fahr. with a moderately stiff brush, and was then worked in with a stiff horse-brush. While the surface was still moist from this treatment the hot soap solution was applied in the same manner. One treatment with each solution in the manner described above constituted a coat. If other coats were deemed necessary, they were applied in a manner similar to the first coat, after the preceding coat had been allowed to stand twenty-four hours or more. The work of application was carried on by two men, one applying the solution and the other following and working it in as described above.

No actual tests were made to determine the imperviousness of the concrete after treatment, but the structures that were repaired and treated have gone through two severe winters and no further disintegration of the concrete on any part thereof has occurred.

Gate Houses of Croton Reservoir.* In the New York City Croton Reservoir the face walls of the back bays of gate houses were built of hard-burnt brick laid in cement mortar. A space between the walls 4 feet wide was filled with concrete. The brick walls were 12 inches thick and 40 feet high and impounded water under a head of 36 feet. When the reservoir was first filled and water let into the gate houses, it filtered through the walls to a considerable amount.

The Sylvester process for repelling moisture from external walls was used to waterproof the walls of these gate houses. This consisted of two washes or solutions for covering the surface of brick walls, one composed of castile soap and water and one of alum and water. The proportions were $\frac{3}{4}$ pound of soap to 1 gallon of water; and $\frac{1}{2}$ pound of alum to 4 gallons of water, both substances being perfectly dissolved in the water before being used.

The first, or soap wash was applied, at boiling heat, with a flat brush, taking care not to form a froth on the brick work. This wash remained twenty-four hours so as to become dry and hard before the second or alum wash was applied; which was done in the same manner as the first. The temperature of this wash when applied was between 60 and 70 deg. Fahr. At least twenty-four hours elapsed before a second coat of the soap wash was put on. These coats were repeated alternately until the walls were made impervious to water. Four coatings rendered the brick wall impermeable under a pressure of 40-foot head. The cost was about ten cents per square foot for four coats.

Retaining Walls, Rock Island Railroad. The retaining walls and abutments on the Chicago track elevation work of the Rock Island Railroad Lines are waterproofed with a coal-tar pitch composition applied to the back of the walls. The expansion joints of these walls were waterproofed by placing a strip of burlap and felt over each joint and mopped with the same composition. Later observations showed these coatings to be satisfactory.

Beaver Park Dam.† The Beaver Park Dam in Colorado is a masonry structure of the rock-fill type. It was made watertight by the application of reinforced concrete facing to its upstream face, as indicated in Fig. 116. This concrete face was placed with no rods or ties to secure it to the rubble face of the dam, as the interstices in the rubble face were depended upon to give sufficient

* Abstract of Paper read before the American Society of Civil Engineers by Mr. Wm. L. Deardon, May 4, 1870.

† Engineering News, Vol. 73, April 8, 1915.

bond between the concrete and the hand-laid wall. The concrete is reinforced horizontally and vertically with wire fabric of diamond mesh, the main wires being No. 4 gauge, spaced 5 inches apart. No expansion joints were provided, and although the concrete face has been exposed to severe temperature conditions, few or no temperature cracks have occurred.

The concrete in the lower portion of the wall forming the water face and in the gate tower was of 1 : 2 : 4 mixture, the aggregate consisting of crushed trachite, while the upper portion of the wall and tower was made of a mixture consisting of practically equal parts of sand and gravel. Up to a point about 20 feet below the crest, a calcium-oleate waterproofing compound was added to the water used to gauge the mixture. The specifications provided that one part

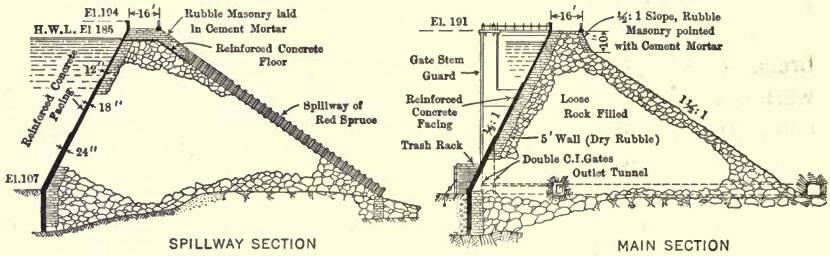


FIG. 116.—Sections through Beaver Park Dam Showing Waterproof Facings.

of the compound was to be added to an equal amount of water and thoroughly dissolved, after which eleven more parts of water were to be added, and this solution used in mixing the concrete for all 24-inch walls and a somewhat weaker solution for thinner walls. The results obtained by using this compound seemed so unsatisfactory to the engineer, that its use was ordered discontinued, and extra cement was added to the concrete at the same cost, which gave much better results.

Queensboro (Steinway) Tunnel. The Queensboro tunnel in New York City (formerly known as the Steinway tunnel), is about 80 feet below ground-water level in water-bearing rock. In its reconstruction the stations were enlarged and waterproofed. It was proposed to waterproof one very large station by the membrane system, and two remaining small ones by the surface-mortar-coating system. The membrane was to consist of six plies of treated fabric laid in coal-tar pitch and applied over the arch as shown in Fig. 117. For lack of head room and on account of the great expense involved in securing this head room the membrane was not installed. In-

stead, a waterproofed surface mortar-coat was applied. In 1916 the two small stations and a portion of the very large station were treated with a 1-inch mortar coat, waterproofed with a proprietary liquid compound composed of a mixture of calcium chloride and a

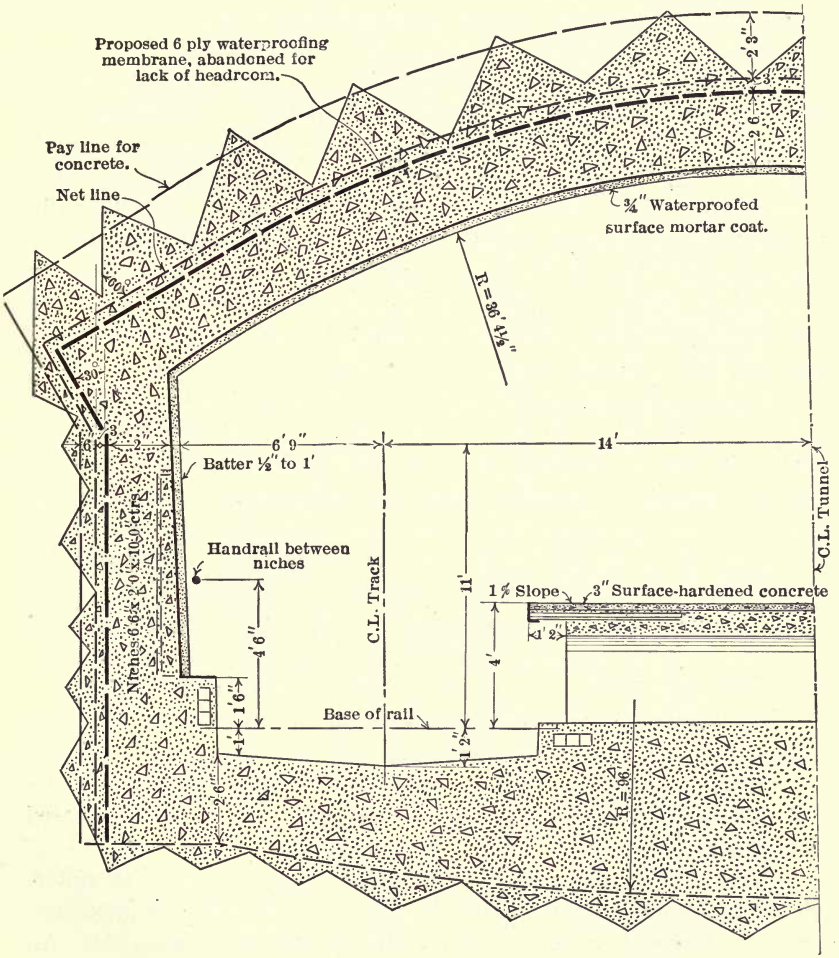


FIG. 117.—Typical Half-section through Station.

carbohydrate and applied with a trowel on the inside of the arch and sides. This surface mortar coat contained about 7 per cent of the waterproofing liquid (added to the gauging water) was easy to apply but troublesome after application, required repairing, and even then it did not remain entirely impervious thereafter. In 1917 the remain-

ing and major portion of the large station was waterproofed by the application of a similar mortar coat $\frac{3}{4}$ inch thick, made of a 1 : 2 mixture containing an alum-soap paste compound mixed in the proportion of one part paste to fifteen parts of gauging water. As a result of this work the leakage was markedly reduced. Some blasting in the vicinity may have contributed to the difficulty of making these waterproofed mortar coats entirely impervious.

Nashville Water Works Reservoir. In repairing and waterproofing the Nashville Water Works Reservoir * precaution was taken against cracks opening at the junction of the new masonry with the old, by using a flexible U-shaped, heavy, sheet-lead stop joint. This was inserted by cutting a dove-tail groove in the concrete core from bottom to top of the ends of the old wall, and by anchoring one end of the lead joint therein with rich concrete in advance of the new masonry, but leaving the other end free. The fold in the joint was protected with tar felt to assure free movement, and the new masonry was built around the free end thereof. This contrivance was simple, effective, of very little trouble, and inexpensive. See Fig. 118. For waterproofing the interior face of the walls, the cement gun was used and the work proceeded in the following manner: The walls were first thoroughly cleaned of all scale and foreign matter by means of pneumatic-hammer chisels so as to afford sound stone faces for the mortar. By the same means the old mortar joints were gouged out to depths varying from 1 to 3 inches for the cement-gun mortar. The walls were then sand-blasted and sprayed immediately in advance of the cement-gun, resulting in clean, sound, stone faces and mortar joints.

The cement-gun mortar, composed of one volume of Portland cement to three volumes of clean sand, followed right behind the sand blasting and spraying before the walls could dry. The whole interior of the walls, including the new masonry, was thus coated and made watertight.

Before laying the asphalt-treated felt membrane used to waterproof the floor, the old concrete floor was carefully cleaned and flushed off with a powerful stream, and all loose scale removed. All rough places and sharp depressions were then filled and brought to a smooth plane with rich cement mortar. After thoroughly drying, the floor was well painted with a priming coat of asphalt dissolved in naphtha. This was followed with a very heavy coat of asphalt heated to a temperature of about 325 deg. Fahr. The asphalt-treated felt followed closely behind this mop coat, in alternate layers

* Engineering News, Vol. 73, May 6, 1915.

of felt and heavy mop coats. Each layer of felt was carefully rolled down before the succeeding coat and next layer of felt were applied, care being taken to squeeze out all the air bubbles. The felt over-

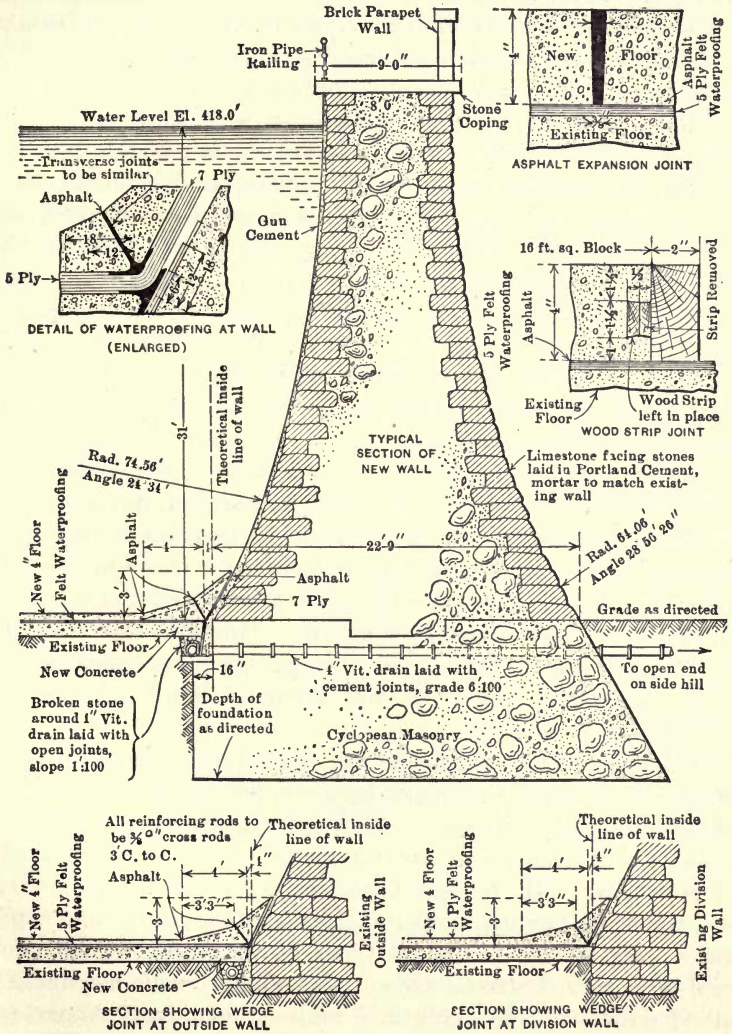


FIG. 118.—Showing Waterproofing Details of Nashville Reservoir Wall and Floor.

lapped and broke joints 3 inches on longitudinal edges and 10 or 12 inches on ends. Five layers of the felt were employed, ending with a heavy mop coat all over the top.

The reservoir, repaired as above described, was for all practical purposes watertight for over two years. In May, 1916, it was emptied during the warm weather for cleaning. During the process of cleaning and removing the mud out of the basin, the cement-gun mortar was exposed to the sun's rays, and badly checked and cracked. These defects were corrected by cutting the mortar out of all visible checks and cracks to the original masonry. These cut-out cracks were then filled with cement gun-mortar. A water curtain was then provided to sprotect the walls from the effect of the sun's rays. This was accomplished by means of a perforated pipe laid around the inner edge of the top of the wall, from which the water trickled down and spread over the mortar lining. By these means, the basin was again made watertight.

The Hudson-Manhattan Tunnels.* Wherever work was executed by open-cut methods on the Hudson-Manhattan Tunnels, between New York and New Jersey, the structure was waterproofed with treated fabric and coal-tar pitch applied in the usual manner, making a complete envelope around it. As the greatest part of this work, however, was executed by tunnel methods this manner of waterproofing was not feasible except in small portions of the work. The method adopted, therefore, was invariably to grout with Portland cement in the rear of the cast-iron ring lining or concrete lining, and in the majority of cases this application answered the purpose of making the tunnels perfectly watertight. Owing to the imperviousness of neat cement this was the only waterproofing adopted on the coffer-dam walls of the Church Street terminal and approaches.

In the iron-lined sections of the tunnel all joints of the plate segments were made watertight by grommetting the bolts with flax and red lead under the bolt washers, and calking the spaces between the joints of the plate lining with a thread of lead wool, followed up and supported with rust-joint cement. Throughout the concrete work, waterproofing was done by plastering the internal and exposed surface with one of the usual types of waterproofing compounds mixed with neat Portland cement and applied with a trowel, this method answering admirably in a majority of cases. At the same time, in persistent leaks, it was found necessary to cut right back into the concrete and expose the voids and then reconstruct such portion of concrete with a rich mixture of cement. As a general rule, for waterproofing of concrete work a rich mixture of cement in

* "Subways and Tunnels of New York," by G. H. Gilbert, Lucius I. Wightman and W. L. Saunders.

the concrete with thorough and efficient ramming answered the purpose and constituted the only waterproofing used.

Reinforced Concrete Standpipe. At Attleboro, Mass., a large reinforced concrete standpipe, 50 feet in diameter, 106 feet high from the inside of the bottom to the top of the cornice, and with a capacity of 1,500,000 gallons, has been constructed and is in the service of the waterworks of that city. The walls of the standpipe are 18 inches at the bottom, and 8 inches at the top. A mixture of 1 part cement, 2 parts sand, and 4 parts broken stone, the stone varying from $\frac{1}{4}$ inch to $1\frac{1}{2}$ inches, was used. The forms were constructed, and the concrete placed, in sections of 7 feet. When the walls of the tank had been completed, there was some leakage at the bottom with a head of water of 100 feet. The inside walls were then thoroughly cleaned and picked and four coats of plaster applied. The first coat contained 2 per cent of hydrated lime to 1 part of cement and 1 part of sand; the remaining three coats were composed of 1 part sand to 1 part cement. Each coat was floated until a hard, dense surface was produced; then it was scratched to receive the succeeding coat.

On filling the standpipe after the four coats of plaster had been applied, the standpipe was found to be not absolutely watertight. The water was drawn out; four coats of a solution of castile soap and one of alum (Sylvester process) were applied alternately, and under a 100-foot head, only a few leaks then appeared. Practically no leakage occurred at the joints; but in several instances a mixture somewhat wetter than usual was used, with the result that the spading and ramming served to drive the stone to the bottom of the batch being placed, and, as a consequence, in these places, porous spots occurred. The joints were obtained by inserting beveled tonguing pieces, by thoroughly washing the joints and covering them with a layer of thin grout before placing additional concrete.

Examples of Membrane Applications

East View Tunnel.* Tunnels are usually not waterproofed by the membrane system because of the difficulty of applying the membrane and making it adhere to the arch. Therefore the grouting process is generally used. The surface-coating system can also be used successfully, but the materials must be carefully chosen and applied. But it may be impossible to employ either of these systems with good results because of the presence of disintegrating agents in the soil

*New York Board of Water Supply Report 1916, p. 135.

or rock through which the tunnel passes. Under such condition the membrane system is best used, and a case in point is the following: A 1700-foot portion of the East View Tunnel of the New York Catskill Aqueduct was built in rock containing iron pyrites from which the compound, sulphuric anhydride (SO_3) is dissolved by the ground water, forming sulphuric acid. This solution, percolating through the seams of the rock, attacked the limestone aggregate of the concrete and also the cement sufficiently to cause disintegration in the concrete lining of the tunnel. It was therefore decided to waterproof this section by means of a 3-ply bituminous membrane. The method pursued in doing this work was as follows: To the face of the partly disintegrated lining was nailed, shingle fashion, No. 28 gauge sheet iron. This acted as a shedding surface for the drip and a dry-ply upon which the membrane was applied. The fabric, which was 3 feet wide was cut up into 6-foot lengths preparatory to applying same. Hot asphalt was mopped on the sheet iron over an area equal to about half the width of the 6-foot strips. Then a strip of fabric was applied (transversely to the center line of the tunnel) and pressed into the binder. The other half of the strip was similarly applied. The second and third plies were laid up likewise, the top ply receiving a final coating of asphalt on its entire surface. Within and against this membrane a brick wall, 1 foot thick, was built completely around the waterproofing.

On the completion of this work the cracks and crevices in the semi-disintegrated concrete, and also the space between the sheet iron and the concrete lining, were grouted. For this purpose 3-inch pipes were attached to the sheet iron and waterproofed around the joint before the brick wall was built. The results obtained by this method of waterproofing the tunnel proved entirely satisfactory.

The asphalt used on this work was a Mexican refined asphalt with a penetration of .55 cm. at 77 deg. Fahr. The fabric was a saturated cotton drill. The asphalt was heated in the tunnel in a rectangular kettle whose source of heat was a battery of gasoline torch burners under it. The gas, contained in a tank under pressure, consisted of about one part gasoline to four parts kerosene.

Long Island Railroad Subway. The Atlantic Avenue section of the Long Island Railroad * in Brooklyn, N. Y., is built of concrete (see Fig. 119). The 5-foot arches, forming the roof are supported by transverse I-beams. This roof was waterproofed in the following manner: After the concrete had thoroughly set and been well dried out by the sun, the upper surface was swabbed over with

* " Modern Tunnel Practice," by D. McNeely Stauffer.

hot, medium-hard, coal-tar pitch such as will soften at a temperature of 60 deg. Fahr., and melt at a temperature of 100 deg. Fahr. as determined by the cube-in-water method. The coal-tar pitch was put on until it had a uniform thickness of not less than $\frac{1}{16}$ inch. Immediately upon the first coat, and while it was still melted, was laid 1-ply of felt, lapping at least 4 inches on all cross-joints, and at least 12 inches upon all longitudinal joints. The felt was at once covered with a uniform thickness of the coal-tar pitch, and upon that was laid a second ply of felt which was also covered by not less than $\frac{1}{16}$ inch of coal-tar pitch. This membrane extended over the ends and down

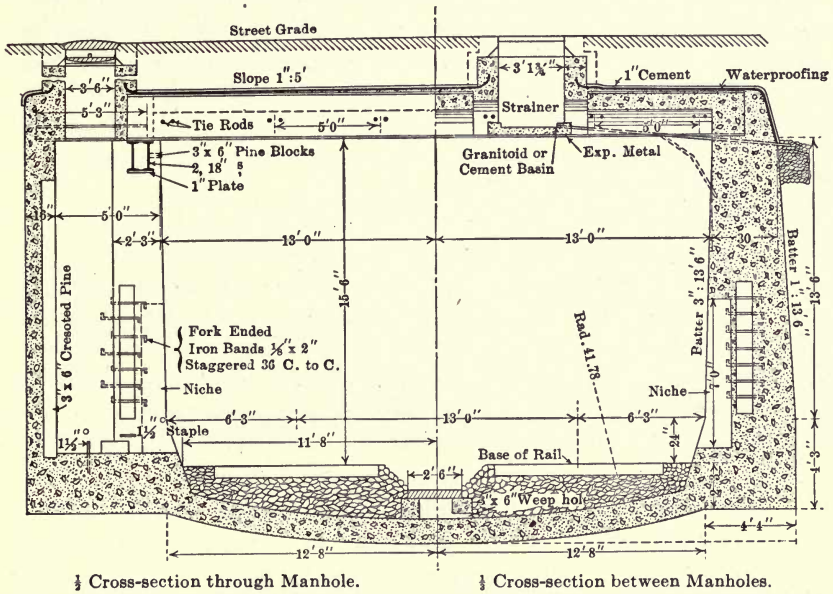


FIG. 119.—Cross-section of Atlantic Avenue Subway, Brooklyn, New York.

the sides, as shown in the cross-section. After the waterproofing had thoroughly hardened, a 1-inch layer of Portland cement mortar was laid uniformly over it with a trowel. This mortar coat was laid in 5-foot squares alternately for the purpose of providing for expansion and contraction. The work was accomplished without difficulty and with very good results.

Manhattan-Bronx Rapid Transit Subway. The first Rapid Transit Subway in New York City built and finished between 1900–1906, was waterproofed with a membrane composed of two to eight plies of felt, each mopped with hot asphalt, as laid. On several small sections of the subway, the felt waterproofing was made more

effective by the application of one or two courses of hard-burnt brick laid in hot asphalt mastic. This was generally against the 2-ply membrane. The membranous waterproofing on the exterior surfaces of the masonry shell made it unnecessary to provide an extensive system of drains or sump pits of any magnitude, for the collection and removal of water from the interior of the subway. A few leaks have developed, mainly due to enlarged cracks, which required extensive repairs; but in general the waterproofing is good after twelve years' service.

The Dual Subway System, New York City.* Two types of waterproofing were used on the 48 miles of new two-, three-, and four-track subways, viz., the bituminous membrane and the brick-in-mastic envelope (the latter, described under examples of mastic applications), the former on the roof between stations and on side walls at stations when above mean high or ground water; the latter both at and between stations on roof, side walls and floor when below mean high or ground water. See Table XXI for details.

The fabric used for the membrane was $7\frac{1}{2}$ and 8 ounces open-mesh, jute burlap saturated and coated with bitumen.

The application of the membrane to the roof is typical of its general use on the entire structure. The concrete roof was swept clean and all surface projections chipped away. The smooth surface, if dry, was then carefully mopped with coal-tar pitch, using ordinary wash mops for this purpose. The treated fabric was carefully unrolled on the mopped surface (see Fig. 120) stretched across the entire width of the subway, where possible, overlapping $1\frac{1}{2}$ feet on either side. As it was unrolled it was pressed into the still hot coal-tar pitch and its surface mopped. A bond with the first coat of binder on the concrete surface was thus made through the open-mesh of the fabric. A second ply of fabric was then applied so that it broke joint either at the middle or at the one-third point of the width of the fabric. The surface of this layer was similarly mopped. A third strip of fabric was applied, breaking joint over the second and carefully pressed into the still hot binder. This process continued until the required number of plies were laid. The surface of the top ply then received a final coating of binder, leaving it smooth. The waterproofing membrane that was thus formed was allowed to cool after which a 4-inch protective coat of concrete was placed thereon extending over the entire width of the subway.

* Public Service Record, published by the Public Service Commission for the State of New York, First District, November, 1915. D. L. Turner, Chief Engineer.

At the time of its application the pitch had a temperature of 325 deg. Fahr. in warm weather and 375 deg. Fahr. in cold weather. No waterproofing was done during an air temperature below 34 deg. Fahr.

A few leaks developed during construction, but almost without exception proved to be due to careless workmanship, such as tares or punctures or foot-square holes accidently left unwaterproofed on the removal of struts and shores.

FIG. 120.—Showing Method of Applying Treated Fabric on Roof of Subway. (Note Rolls of Fabric, Pitch-carrying Pails, and Mop.)

Bergen Hill Tunnels, Pennsylvania Railroad.* In waterproofing the Bergen Hill tunnels of the Pennsylvania Railroad System, three general types of construction for the arch were decided on, as shown in Fig. 121. The first, as shown at *A*, was to be used where the tunnel was quite dry. In this type the sand wall was omitted entirely and the concrete and rock packing were built up together, the rock packing impinging to a certain extent on the concrete and the concrete squeezing somewhat into the rock packing. The section shown at *B* was used where the tunnels were damp or where there were slight droppers, not forming a continuous stream. The back lagging of 1-inch boards, which was left in place provided a practically smooth outer surface on the concrete arch and allowed the concrete and rock packing to be built almost simultaneously. It was con-

* Transactions of the American Society of Civil Engineers, Vol. 68, p. 142.

sidered that the free drainage through the rock packing, the surface of the boards and the smooth outer surface of the concrete in the arch would allow the comparatively small quantity of water in these parts of the tunnel to find its way to the sides, thence to the ditches at the bottom, rather than percolate through the concrete. This proved to be very generally the case, as is shown by the dry condition of the tunnel as built. The back lagging was used over the arch,

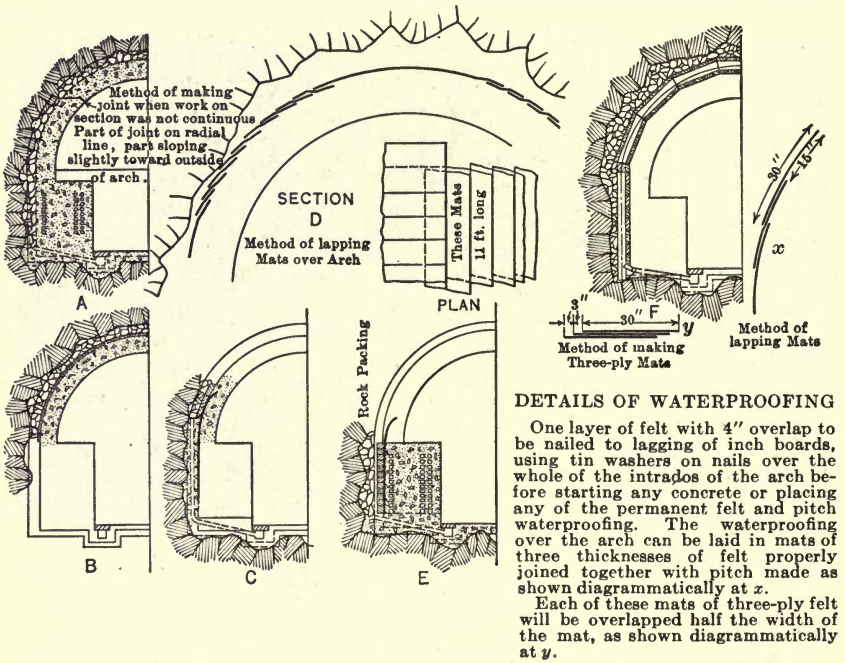


FIG. 121.—Various Types of Arch Waterproofing Used on Bergen Hill Tunnels.

both where the sand wall was built and where it was omitted, as well as being placed over the waterproofing of the arch as an armor course where waterproofing was required. Where the sand walls were built and waterproofed, and where the waterproofing was not carried over the arch, the waterproofing was turned in at the top, as shown at *C*.

The third method provided for waterproofing the whole of the arch. This was the same as *B* except for the addition of the waterproofing inside the back lagging. In placing this waterproofing, the felt was cut in strips about 11 feet long (about 1 foot longer than the length of a section of arch) and six thicknesses were cemented

together with hot coal-tar pitch. These mats were then laid, shingle-fashion, as shown at *D*, up the sides of the arch until a space about 5 feet wide remained at the crown; shorter mats were then brought out over this, laying them perpendicular to the axis of the tunnel. Care was taken in making all laps, irrespective of the direction in which the arch was built, so that they would lay with the grade, that is, so that the water would tend to flow over the edges of the laps rather than against them.

The method of waterproofing that part of the timbered section which was very wet is shown at *F*. A lagging of 1-inch boards was nailed up the sides and to the soffit of the segmental timbering, all the spaces outside of this lagging being carefully filled with rock packing. Before starting any concrete work a single thickness of waterproofing felt was nailed to the inner side of the lagging, which not only served to protect the finished surfaces of the concrete from the water which fell copiously from the roof, but also provided a comparatively dry surface to which the regular 6-ply waterproofing could be cemented with pitch and held in position while the concrete was placed against it.

Boston Tunnels.* A section of the Boston, Mass., subway consists of two tunnels underneath the Fort Point Channel. These tunnels are built with an outer shell 9 inches thick made of Southern long-leaf pine-wood segments and an inside concrete shell 2 feet thick (minimum) with steel reinforcement. These tunnels are waterproofed by the application of a bituminous membrane to the interior of the wooden shell before placing the interior concrete lining (see Fig. 122). This membrane consists of layers of treated cotton fabric mopped with hot asphalt. Two layers are put on the invert and three on the sides and arch. In applying the waterproofing to the sides and arch, the first layer of cloth was mopped on one side with asphalt and then nailed to the wooden lining with roofing nails, the mopped side being against the wood. The second and third layers were then stuck on with successive moppings of hot asphalt. The result after three years' service is entirely satisfactory.

Waterproofing Railroad Viaducts. The following unique method of waterproofing the Martins' Creek and Tunkhannock Viaducts on the new line which the Lackawanna Railroad has recently built west of Scranton, Penna., is described as follows by Mr. G. J. Ray, Chief Engineer.† "The structures referred to were treated alike, the same waterproofing materials being used in each case. The

* Engineering Record, August 21, 1915.

† Engineering News, Vol. 75. March 2, 1916.

floor system over each main arch is divided into three parts by four transverse expansion joints—two adjacent to each pier and one at each of the quarter points of the span. The floor is drained by downspouts through all spandrel walls, excepting those at the two intermediate expansion joints, and the drainage is discharged into the openings between the two ribs of the main arch. The drainage is prevented from flowing over the expansion joints by dikes built across the floor (enlarged details are shown in Fig. 123).

"The waterproofing proper was done by using three plies of saturated cotton fabric laid in hot asphalt. The concrete was first

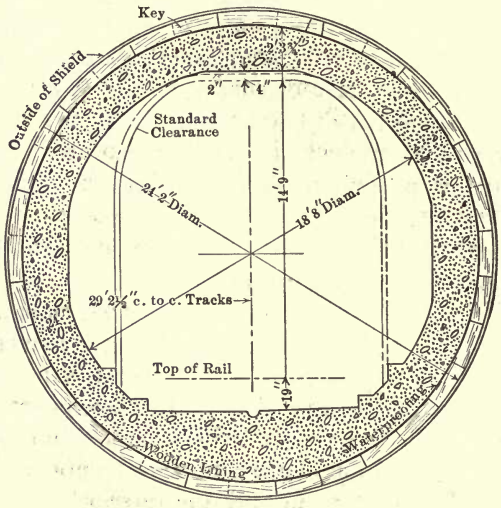


FIG. 122.—Waterproofing is Placed against Wooden Lining and Outside of Concrete on Shield-driven Tunnel, Boston, Mass.

mopped with the hot asphalt. The three layers of cloth were then laid in the usual manner, each layer being mopped before the application of the succeeding layer. This waterproofing was carried up the sides of the parapet wall to the top of the ties and directly across all expansion joints, so that the waterproofing was in reality continuous from one end of the bridge to the other. At the expansion joints one additional layer of the saturated fabric was laid across and folded in the expansion joint beneath a copper flashing, similarly laid, over which the three layers of waterproofing were placed. A fold was provided in the waterproofing at the joints to provide for expansion and the entire joint filled with the hot asphalt.

"As a protection to the waterproofing, asphalt-mastic mixed with washed torpedo gravel, was applied hot in two $\frac{3}{4}$-inch layers over the entire area of the waterproofing. In order to avoid injury to the waterproofing by the hot mastic, 1 ply of asbestos felt was first laid

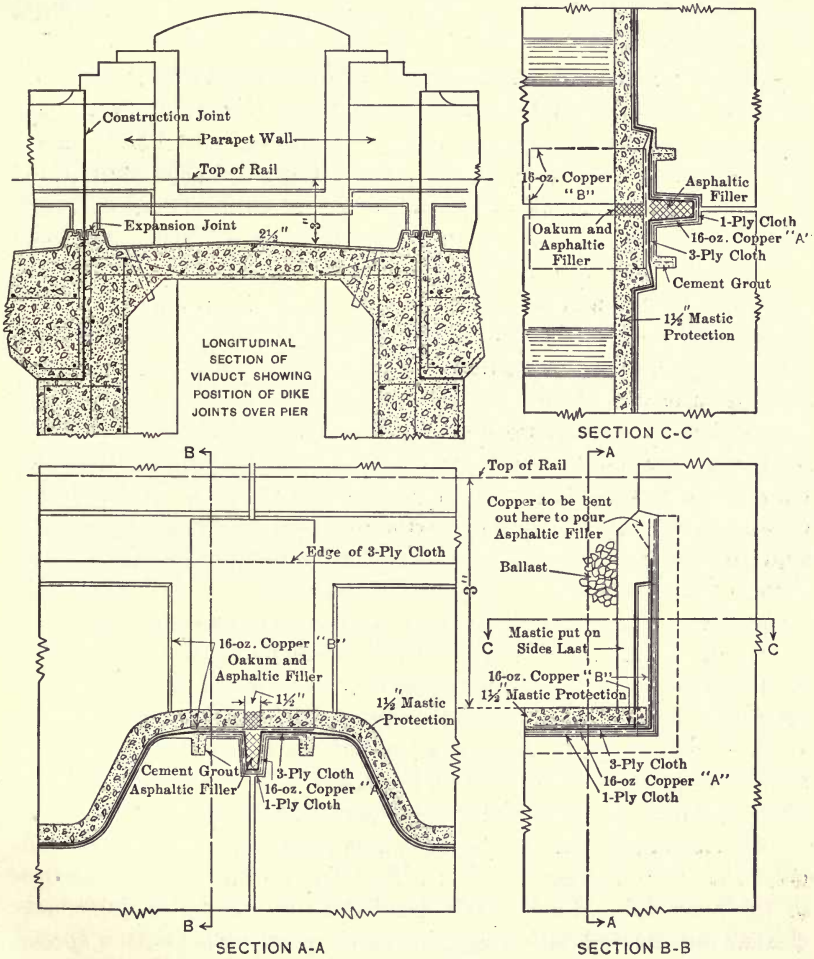


FIG. 123.—Dike Form of Expansion Joint, and Details of Waterproofing on the Martin's Creek Viaduct.

over the entire area of the membrane. An opening was left in the mastic directly over the center of each expansion joint and filled with the hot asphalt. The asphalt-mastic was used for protection in preference to brick or concrete, since our experience elsewhere with this mastic, under ballast, indicates that it does not crack and in reality

forms a secondary waterproofing surface on which the drainage readily passes to the downspouts."

Terrace, United States Capitol. The pavement over the terrace chambers of the United States Capitol at Washington, D. C., has been made watertight by the membrane system after many failures by other systems.*

Many methods of waterproofing have been tried on this great expanse (about 200,000 square feet) of walk, to wit: felt and coal-tar pitch, asphalt and burlap, sheet asphalt, etc. In 1906 a sheet-lead pan was placed under one section. The sheet lead was bedded in cement mortar on the base slab and was covered with a 3-inch reinforced concrete slab and a 1-inch wearing surface. But even this construction was of no avail, partly because of the extreme expansion movement, partly because of unskilled burning of the sheet joints and partly because of the inherent difficulties of flashing around the vault light frames. The sheet lead on being uncovered was found to be considerably pitted.

The expansion and contraction movements of the terrace structure are excessive, owing to wide variations in temperature and extreme exposure. Insufficient provision was made for inevitable expansion movement, and to this defect can be finally traced the repeated failures to keep the terrace chambers watertight. Final success was largely due to recognizing expansion difficulties and providing for such movement by watertight, sealed expansion joints.

Specifications were issued for this work in 1914. The notable features of these specifications consisted (1) in securing a bituminous compound having maximum adhesiveness and cohesion, (2) in using small (1 square yard) freshly saturated cotton fabric sheets, with wide laps, mopped into place and covered with protective masonry, (3) in the free use of special expansion and flashing joints.

The material over the terraces was removed down to the concrete slab over the floor arches which disclosed numerous fractures in the base slab. Each crack, treated as an expansion joint, was cleaned out, heated with a gasoline torch, partly filled with a special asphalt compound and tooled with a hot iron as shown in Fig. 124. The slab was also cut for expansion joints, as shown in Fig. 125.

After the expansion joints were filled, the pavements were brought up to subgrade by a filling of 1 : 3 : 6 concrete. Upon the leveled subgrade was laid single sheets of impregnated cotton drill. The sheets were 1 yard square and were laid with 2-inch laps. A small area of subgrade was cleaned and mopped with hot compound just

* Engineering News, Vol. 76, No. 14, October 5, 1916.

previous to laying each sheet. The laps were made tight by following with a hot smoothing iron. Upon the membrane thus made there was laid, as armor for the waterproofing and as a wearing surface, a granolithic pavement (1 : 1 : 2 mixture with $\frac{1}{2}$ to $\frac{3}{4}$ inch washed bluestone chips), marked off in squares. These squares were separated by expansion joints continuous with the expansion joints in the subbase, as shown in Fig. 125, also along the balustrades, vault lights, and at every point where flashing would ordinarily have been employed.

In waterproofing the expansion joints, the cut in the bottom slab was heated, painted and partly filled with the asphaltic compound. Then the membrane was brought down into the opening and the joint pointed with mortar. The joint was covered with a patch strip

FIG. 124.—Slab Cracks Made into Expansion Joints in Waterproofing the Capitol Terraces, Washington, D. C.

(see detail *X* on Fig. 125), completing the lower half. When the granolithic paving was laid, wood strips, tapered $\frac{3}{4}$ to $\frac{1}{4}$ inch, were inserted as joint forms. When the concrete had set, the wood was pulled out, the opening heated and partly filled with the compound. The remaining space was pointed with mortar. In this way a covered and sealed reservoir was created at each expansion joint. As the structure contracts and expands, the mortar plug is drawn down or forced out, the seal being preserved. After one summer's use the joints were found all closed nearly tight, demonstrating that by use of a thin plastic membrane underlying the wearing surface the latter could be kept from spalling or cracking.

Manhattan and Brooklyn Railroad Viaducts. In building railroad viaducts through city streets, where space is usually very valuable and scarce, and economy of operation the governing factor in the type of structure required, it has become the practice to construct the stations underneath the track level, instead of projecting

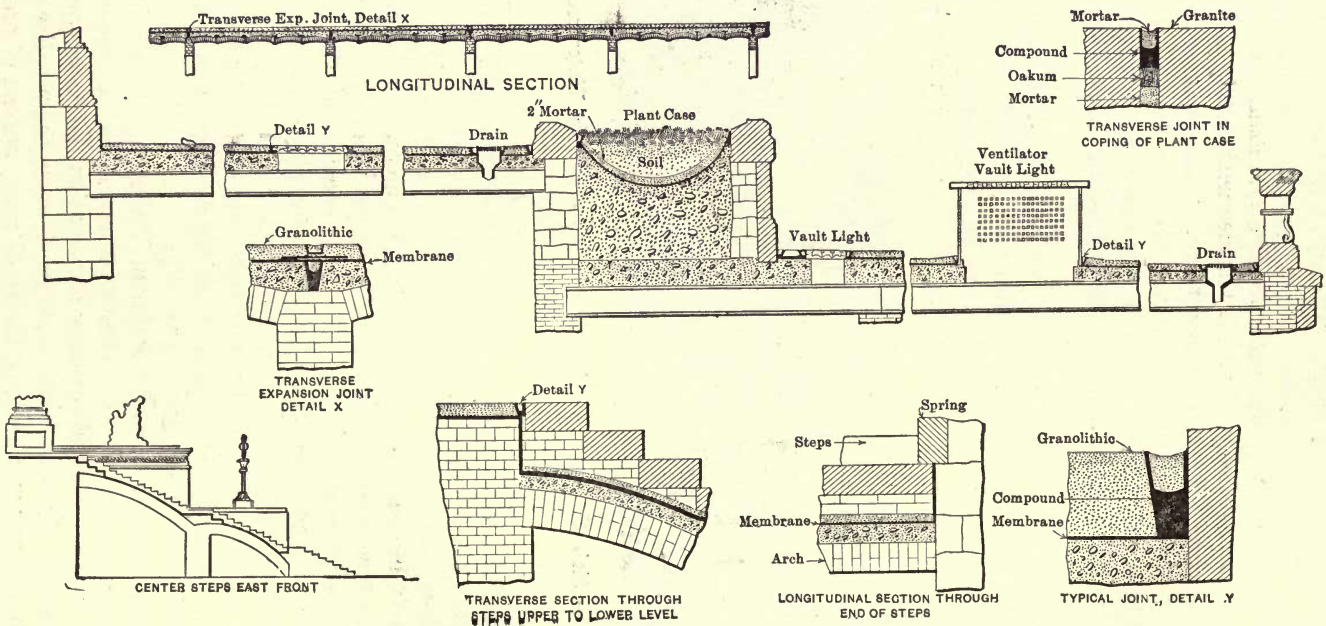


FIG. 125.—Waterproofing Employed on Terraces and East Steps of Capitol, Washington, D. C.

them into the side streets on a level with the tracks. This new practice necessitates the portion of track floor or road bed directly over the station mezzanine to be perfectly watertight. To best accomplish this the steel work at these locations of the elevated

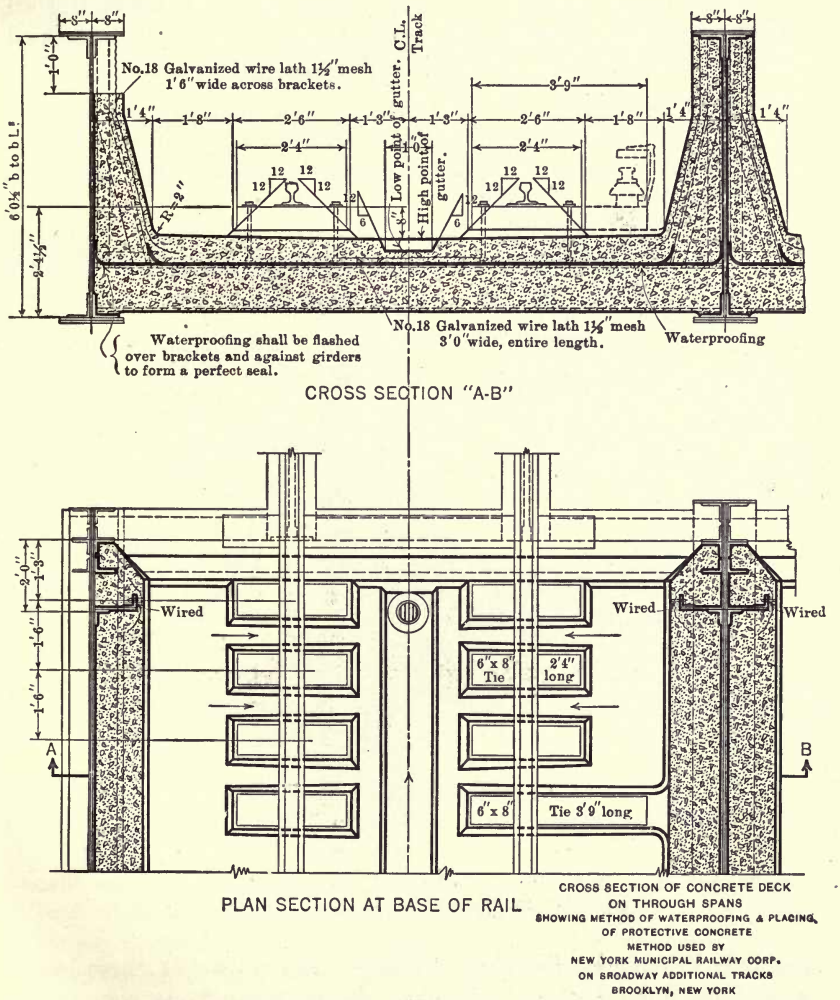


FIG. 126.—Method of Waterproofing Concrete Decks on Through Spans, Used by the New York Municipal Railway Corporation.

structure should be designed free of bays and unnecessary connections, and should also be encased in concrete. This concrete, forming the roadbed, may be constructed in sections as shown in Fig. 128, which is not advisable, or in monolithic form as shown in Figs. 126

and 127. A design very successful in this respect is used by the New York Municipal Railway Corporation of Brooklyn, N. Y., on several of its elevated lines (see Fig. 126).

Waterproofing on the concrete roadbeds over the mezzanine floors of these stations consists of a 2-ply membrane composed of treated cotton fabric and asphalt binder, applied over the concrete and lapped on to the steel girders. Sometimes the ends of the membrane were

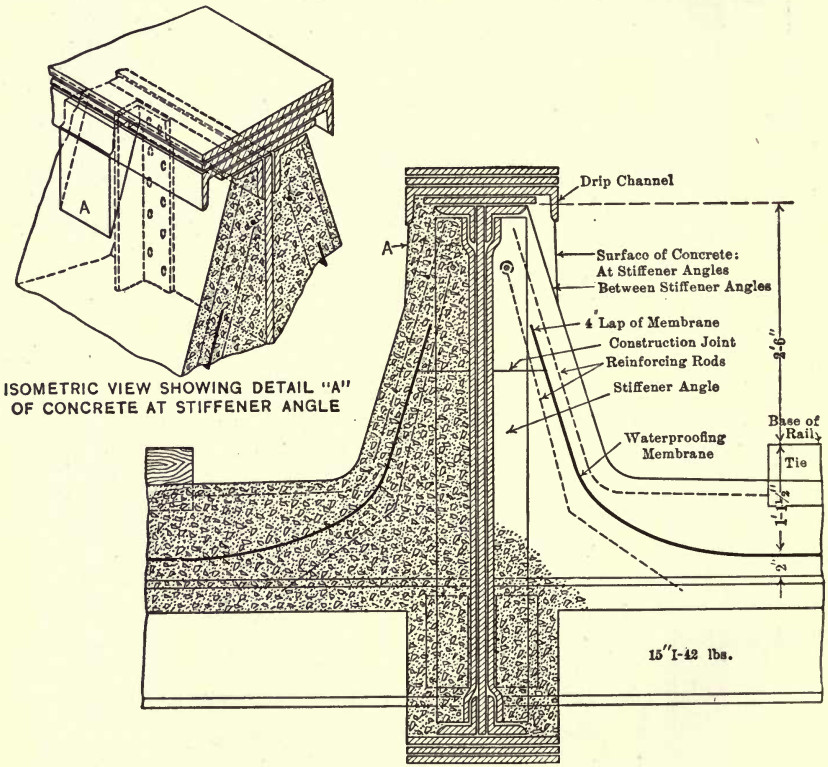


FIG. 127.—Section of Girder of Railroad Viaduct Showing Membrane Waterproofing, Protective Concrete, and Drip Channel.

put into V-joints between the concrete and steel webs; these joints were then filled with an adhesive, elastic, bituminous compound. Over this membrane was placed a minimum of 4 inches of protective concrete. This concrete is brought up the sides of the girders to the top flange in monolithic form. This trough-type construction of track floors has proved very successful. A design even more efficient than the above one, from the waterproofing standpoint, is shown in Fig. 127. In this design a dripping surface is provided by the

substitution of a steel channel for one of the cover plates of the steel girder. Fig. 128 shows the design of a steel and concrete roadbed on a few railroad viaducts in New York City. The waterproofing details, one of which is shown in Fig. 129, were not entirely adequate.

In connection with the design and construction of watertight steel and concrete road beds of railroad viaducts it is proper to point out to the engineer whose duty it is to design the waterproofing for such locations that he would do well to carefully study the details connected therewith. He knows, for instance, that the structure is subject to

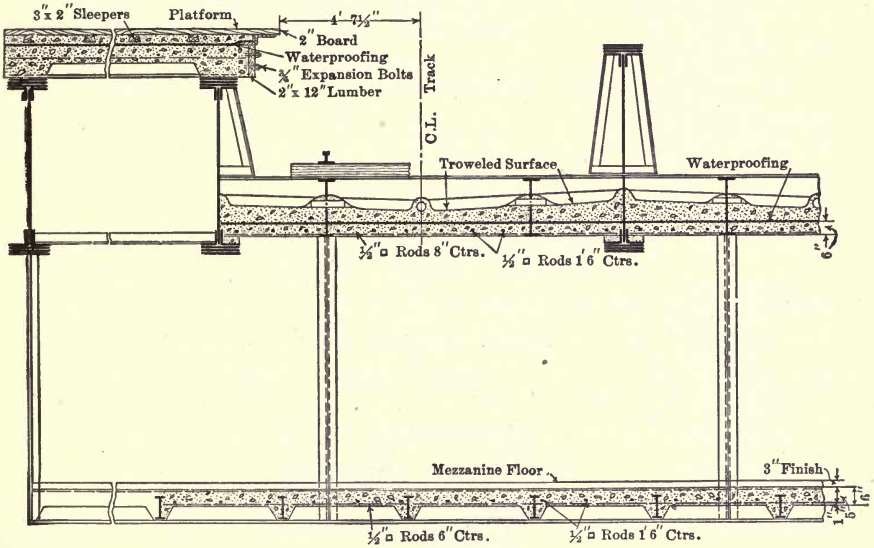


FIG. 128.—Typical Construction of Mezzanine Roof on Elevated Railroad Structures in New York City, Showing Location and Protection of Membrane Waterproofing.

severe vibration; he should know, also, that a comparatively thin layer of concrete or mortar is almost useless for the protection of waterproofing under such conditions. He probably knows that only the membrane or perhaps the surface-coating types of waterproofing are serviceable for such a structure, but he should know also that joints between steel and concrete can remain watertight only so long as the joint filler remains plastic, though even this is doubtful, in view of the difficulties experienced in the design lastly referred to.

Still another feature peculiar to such structures, as shown in Fig. 128, would be revealed by a careful study of details and that is, that

openings, large and small, crevices and pockets in the joints and connections of the steel members which cannot be filled or covered with the bed concrete, require calking. Or else the waterproofing must be carried up the sides of the steel work, suitably protected and high enough to effectually prevent the percolation of water through the joints and connections. Unless either of these things is done no amount or quality of waterproofing of the roadbed proper will make the structure watertight.

The following is a case in point that has been brought to the attention of the author and well illustrates the need for careful study of waterproofing details. Fig. 128 is a cross-section through a steel viaduct where a mezzanine floor, roadbed, and elevated platform are shown.

The purpose of the concrete roadbed is to form a solid roof protection for the structure underneath, and the concrete of the elevated platform serves a like purpose. Now, it is rightly assumed by the engineer that the concrete may crack in the course of time and allow water to seep through to the mezzanine floor below. To obviate this danger he specifies a 3-ply membrane to be laid on the concrete, and covered with a 4-inch protective coat of concrete. Realizing that the protective concrete cannot make a watertight joint with the webs of the girders or beams, the concrete covering is designed so as to leave a V-shaped joint between it and the steel, as shown in Fig. 129.

Even when a good elastic compound is used as a filler, the material cannot last for more than a few years and retain the properties requisite for waterproofing under this condition. Hence, sole reliance upon such a material to always effectively seal the joint, is unwarranted. Still more so is the use of a high melting-point bitumen, such as a hard coal-tar pitch or asphalt, because they become extremely brittle materials at temperatures but little below the ordinary. Almost the first train that would cross the viaduct during cold weather would cause the pitch in the V-joints to crack and break away from one of the two surfaces, after which it would be useless as a means of preventing water from seeping through the joint or getting around and under the membrane. It is a fact that plastic joint fillers have actually failed in this regard; that is, the joints between the steel and the filler opened and nullified the value of the rest of the waterproofing. It is equally a fact that this result is inevitable, because of the varying rates of vibration between the structural materials when a train passes over the structure due to the relatively different inertia of the steel and the concrete.

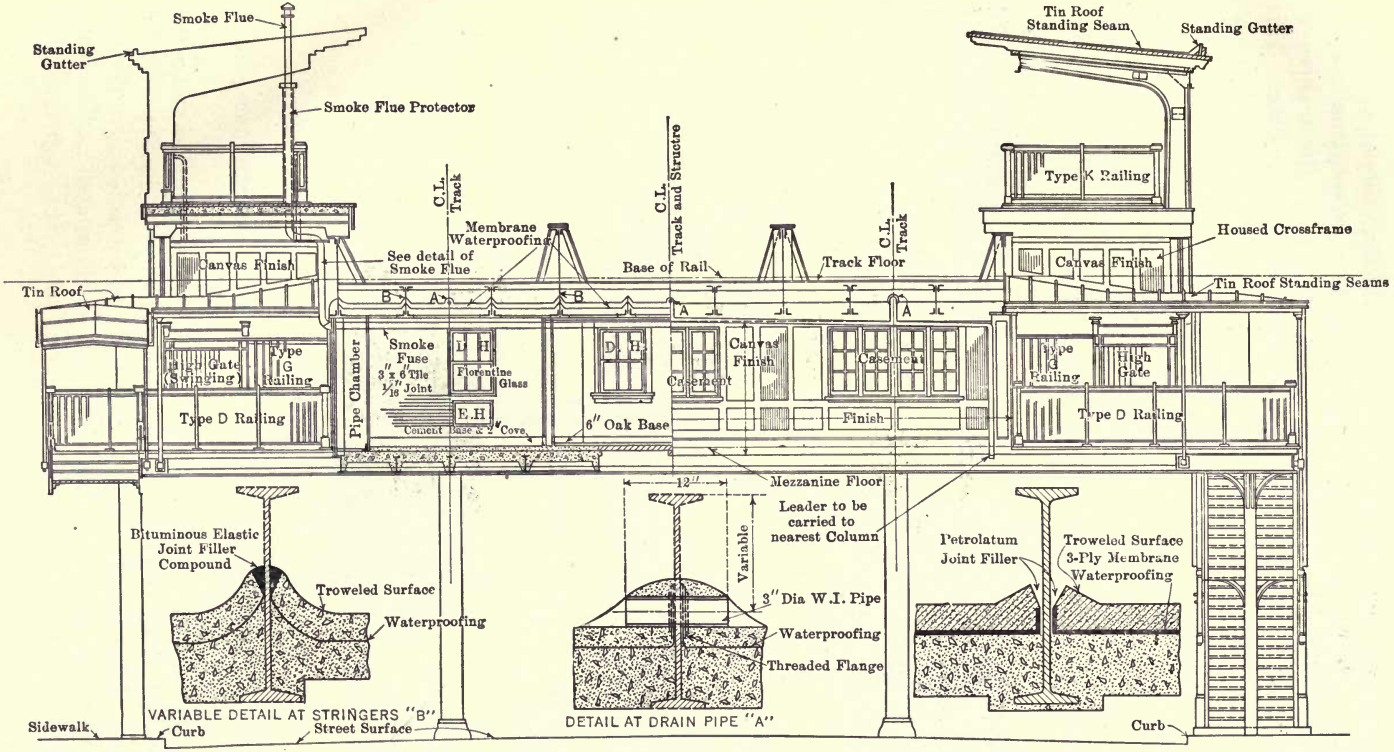
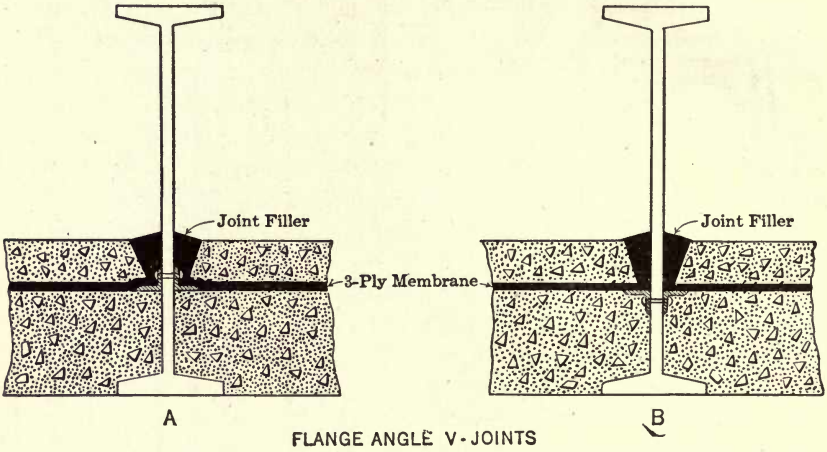


FIG. 129.—Types and Location of V-joints Used to Waterproof Mezzanine Roofs (Track Bases) at New Elevated Structures in New York City.

An arrangement that would prove more efficient, though somewhat costlier, is shown at *A* in Fig. 130. In this form of construction, the effective waterproofing of the structure, or rather, the making of watertight joints is practically independent of the joint filler. This



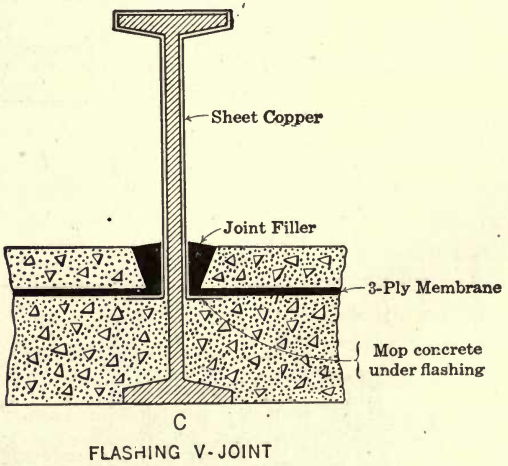


FIG. 130.—Improved Types of V-joints for Elevated Structures.

form of construction may also be modified so as to have the angle iron act as a flashing instead of a joint, as shown at *B* in Fig. 130. A strip of thin sheet lead between the angle and web is recommended. An arrangement, whereby the angle iron is eliminated and a copper flashing substituted, is shown at *C*, Fig. 130. This design is more

efficient than the above two, because if the joint filler should fail to act, it would still be almost impossible for water to get around the flashing and seep through the joint. This design, however, is costlier and requires great care when applying and soldering together the sections of the flashing and in the selection of the metal. In designing the protective concrete, it is often necessary and always advisable to reinforce it with some form of wire mesh of which the transverse ends should be left projecting somewhat into the joint filler. Fig. 131 shows a way to utilize the protective concrete so as to secure watertightness in the track floor. Other methods will undoubtedly

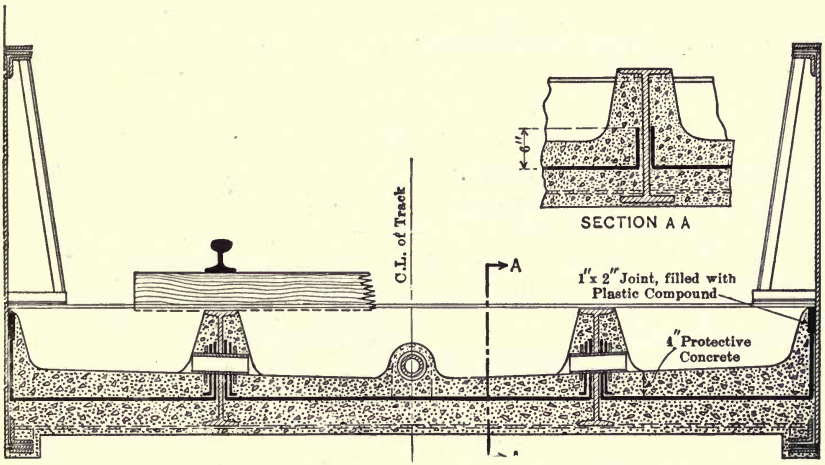


FIG. 131.—Waterproofing Details around Ferrules at Drains, also Showing Increased Utility of Protective Concrete over Membrane on Mezzanine Track Floor of Elevated Structure.

suggest themselves upon careful consideration of the conditions at hand. The purpose of this digression is merely to call attention to the need of studying waterproofing details and carefully selecting the materials.

Perhaps the citation of another glaring instance of an ineffectual design and application of waterproofing will impress the architect, engineer and contractor with the serious consequences following a disregard of the need to study details and understand the selection of waterproofing materials.

A very important station on one of the Brooklyn (New York) Elevated lines consists of a double-deck concrete structure built partly below ground surface. The ceiling above the platform of the lower deck is raised and forms the train platform of the upper

deck. The track floors between the platforms of the upper deck are waterproofed with a 6-ply membrane made of treated jute fabric and coal-tar pitch having a melting-point of 120 deg. Fahr. by the cube-in-water method. This membrane terminates directly over the webs of the platform girders as shown at *A*, Fig. 132. These girders support concrete walls which, in turn, support the platform of the upper deck. The first summer after the station was completed considerable quantities of the binder exuded through and all along the construction joints between this concrete and the top flange of these girders.

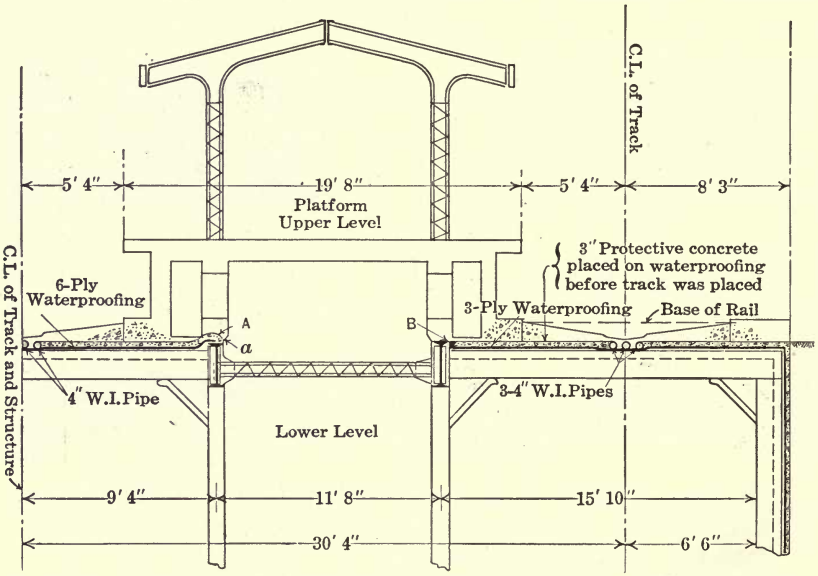


FIG. 132.—Cross-section of Station Platform and Track Floor, Showing Scheme of Waterproofing Proposed and Used on a Sub-level Railroad Structure in New York City.

The resulting defacement of the structure and injury to the waterproofing was, however, not due to a poor grade of material nor bad workmanship in the application of the waterproofing, but was entirely due to faulty design, as is evident from the figure, and the neglect to specify a binder of an asphaltic nature or a coal-tar pitch of at least 30 deg. Fahr. higher melting-point. That this precaution should have been taken follows from the fact that the station has a superstructure which is exposed to the elements and hence the concrete may easily acquire a temperature above 100 deg. Fahr. in the summer time.

Another point worth mentioning is that the purpose of the waterproofing membrane in this particular structure is such as hardly requires more than three plies, and the way this should have been applied is shown at *B*, in Fig. 132, which is self-explanatory.

Waterproofing Reinforced Concrete Standpipes. In the design of reinforced concrete standpipes, engineers have hitherto met with little success in obtaining watertight tanks for several reasons:

1. Because of insufficient attention to proper grading and proportioning of concrete aggregates.
2. Imperfect design of expansion joints (see Fig. 45 for a successful type of expansion joint).
3. Laxity in supervision and workmanship during construction.
4. Insufficient attention to details.

Nearly all standpipes are so conditioned during their use that the concrete, especially the lower portion of the standpipe, is subjected to varying stresses consequent upon changing heads of water. During this action the stresses in the reinforcement likewise vary, hindering the silting up of minute cracks that may have formed and which after a freezing season may become dangerously large.

Hence, it may be concluded that any structure subject to so many different kinds of stresses as is a concrete standpipe is best made waterproof by the application of a bituminous membrane of from two to four plies of fabric or cotton drill applied on the inside, and covered with a coat of mortar $\frac{1}{2}$ to 1 inch thick. This method obviates the need of extraordinary precautions in grading and supervision, and it will also be found that the cost is no greater and results more certain than when using either the integral or self-densified system of waterproofing. This method has been followed in several instances with success.

Waterproofing Floor of Pneumatic Caisson. To aid the engineer in his judgment and to avoid delay in the execution of the waterproofing work in hand, he will do well to resort to some practical field tests for the determination of the working properties of a material or method not heretofore used or not used under extraordinary conditions. A case in point is the following: Specification requirements for waterproofing the floor of a pneumatic caisson used in connection with the construction of two tunnels under the East River connecting the William and Clark Streets subway between the boroughs of Manhattan and Brooklyn (see Fig. 111) called for a "soft pitch which will soften at 32 deg. Fahr. and melt at about 60 deg. Fahr. so that it can be spread without heating." Its use was intended for waterproofing under compressed air where the fumes

of hot melted coal-tar pitch would be unbearable to the workmen and give rise to fire risks. But such a low melting-point coal-tar pitch is not a commonly used waterproofing material and must be made up specially, hence delay and increased cost may result.

The compressed air chamber was under about 20 pounds pressure, and had an air temperature of about 75 deg. Fahr. After completion, the concrete floor and the waterproofing underneath would have a temperature about 20 deg. below this, with the result that the low melting-point pitch would exude from cracks or would tend to flow toward any hollow or other depression in the concrete and perhaps nullify the purpose of the waterproofing. To avoid this condition and still use coal-tar pitch, for pitch was the only material allowed under the specifications, a straight-run coal-tar pitch having a melting-point of about 120 deg. Fahr. by the cube-in-water method, was first tried; that is, it was heated to about 325 deg. Fahr. or over, poured in small buckets and lowered into the caisson. But coal-tar pitch, when heated to a temperature of about 325 deg. Fahr. as was done in this instance, fumes offensively. A test, by the author, to determine the temperature at which fumes commence to be given off by the molten pitch showed that hardly any was given off until a temperature of about 225 deg. Fahr. was reached. Hence all that was required was not to heat the coal-tar pitch beyond this point and a regular, stock material could be used. After a single trial it was used in this manner very successfully. However, in the case of another caisson under about 40 pounds pressure per square inch, the soft grade of pitch called for in the specification was used (necessitated by the greater fire risk) and the work well accomplished.

Waterproofing Steel Swimming Tank.* A swimming tank, 30 by 60 feet in plan, and from 4 feet to 8½ feet deep, situated between the 10th and 11th floors of the Union League Club House in Chicago, was waterproofed by the application of a sheet-lead membrane and a felt membrane against the lead. Before applying the sheet-lead membrane the rivet heads on the inside of the girders forming the sides of the tank were flattened to ½ inch. Over the entire area 1½ inches of cement mortar was put on with a cement gun. Upon this mortar coat the sheet lead, weighing 4 pounds per square foot (about $\frac{1}{16}$ inch thick), was placed and tacked to wooden strips set in the mortar. All the joints were soldered. Then the felt membrane was applied, being bonded with coal-tar pitch, and covered with 4 inches of cement mortar also put on with the cement gun. The entire

* Engineering Record, Vol. 75, No. 3, January 20, 1917, p. 107.

inside was then lined with ceramic tile ¼ inch thick, set in cement mortar.

The above scheme, suggested by the contractor, and which proved very satisfactory, was substituted for the original specification calling for membrane waterproofing with calking and welding of joints to make the steel watertight.

Examples of Mastic Applications

Waterproofing Roadbed Over Mezzanine. Some of the track floors over the station mezzanines on an elevated railroad in Brooklyn, New York, consist of a framework of steel beams and girders with concrete slabs in the open spaces, forming a series of bays (similar to Figs. 128 and 129). These bays are waterproofed with a mastic sheet approximately 2 inches in thickness placed directly on the concrete. Each bay is drained by a pipe to the adjacent one until the water reaches an end but central bay, from which it passes into a copper gutter. The drains are 3-inch wrought-iron pipes, 12 inches long, passing through the steel webs to which they are fastened by means of ferrules and made to adhere to the mastic.

Before the mastic was applied to the concrete slabs, 2-inch strips of the steel webs were mopped at the required elevation with asphalt to secure a good bond between both. The mastic consisted of approximately 12 per cent asphalt, 14 per cent sand, 22 per cent grit, and 52 per cent limestone dust.

Though the mastic was well made and applied, and was in good condition more than a year after application, it gave very poor waterproofing results. This was directly traceable to the poor bond between the steel webs and the mastic, being broken by the severe vibration in the structure and especially the non-synchronous vibration between the concrete slabs and the steel framework.

The Dual Subway of New York City. In waterproofing the new subways in New York City two systems were used. The membrane (described under examples of membrane applications) and the brick-in-mastic envelope (described below). The latter method was used in the manner noted in detail, in Table XXI and illustrated in Fig. 132*A*.

The floor and side walls of the subway below ground or mean high water, when passing through earth, also the roof of stations, were waterproofed by the brick-in-mastic system. This consisted of one or two courses of ordinary building brick embedded in mastic. The mastic was composed of a minimum of one-third asphalt and

two-thirds sand and cement, or sand and limestone dust. It was mixed hot on the work in round-bottom iron kettles of 50- and 100-gallon capacities (see Fig. 77) at a temperature not exceeding 375 deg. Fahr.

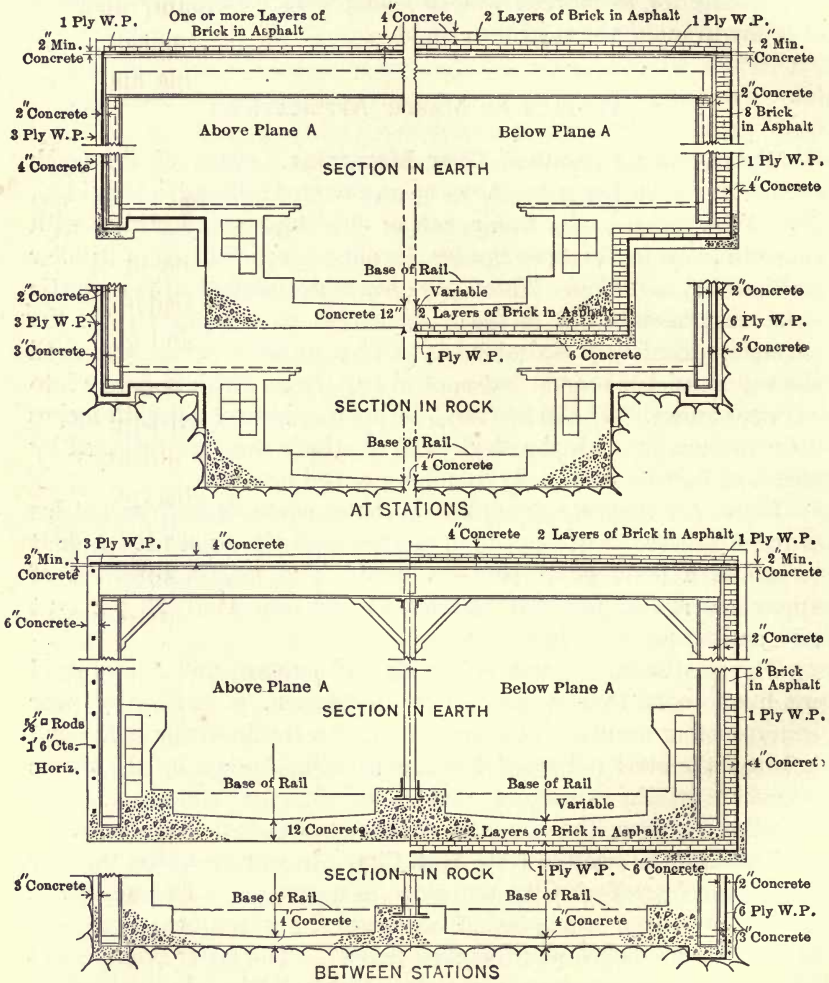


FIG. 132*A*.

In applying the brick-in-mastic to the floor of the subway, the surface of the concrete bed, which was generally from 4 to 6 inches thick, was covered with a single ply of waterproofing felt or fabric, and its surface completely mopped. This served as a dry ply upon which to place the brick-in-mastic envelope.

Two courses of brick-in-mastic were applied to the floor and together had a minimum depth of 5 inches. The thickness of the various brick-coverings of mastic was not less than $\frac{1}{8}$ of an inch (see Fig. 133).

On side-wall construction, the vertical surface of the excavation was first carefully faced with concrete. Forms were placed 8 inches

FIG. 133.—Showing Application of First and Second Layers of Brick-in-Mastic and Method of Sliding Bricks into Place. (Note Mastic Covering Finished Portion between the Two Posts.)

from this facing and the brick and mastic laid therein, as follows. A quantity of mastic was poured into the space and bricks laid in it on their largest bed and in a double row, leaving a minimum of $\frac{1}{8}$-inch joints around all faces. After cooling, the forms were removed and the main concrete wall of the subway was built against the mastic wall. No leaks developed where the brick-in-mastic envelope was used.

Examples of Integral Waterproofing Applications

Waterproofing Reinforced Concrete Reservoir.* In renovating a 1,000,000-gallon reinforced concrete reservoir at New Ulm, Minn., watertightness was secured in the structure by exercising special care during construction to grade the concrete aggregate. Pebbles, varying in size from $\frac{1}{4}$ to $2\frac{1}{2}$ inches screened from a gravel bank, were used in the floor and walls, as experiments had shown that these pebbles made a denser concrete than broken stone. To reduce the permeability of the concrete to a minimum, however, 20 pounds of hydrated lime was used to every barrel of cement. After the forms were removed, the walls were brushed and cleaned with steel brushes, and two coats of 1 : 2 cement mortar, about $\frac{1}{2}$ inch thick, waterproofed by the addition of 10 per cent of finely powdered iron, were applied. The floor was treated with a slush coat of 1 : 2 mortar which after setting received a brush coating of waterproofed mortar. After water was let in some leaking took place and cracks developed which were finally remedied and the reservoir was rendered watertight.

Concrete Tank at Duxbury, Mass. A reinforced concrete tank in Duxbury, Mass., † 40 feet inside diameter and 35 feet high was made watertight by using a rich concrete with an addition of hydrated lime. The bottom is a reinforced concrete slab built in two 12-inch layers, the lower one of 1 : 2 : 4 concrete and the upper one of 1 : $1\frac{1}{2}$: 3 mixture with the addition of 5 per cent hydrated lime. The walls are of 1 : 1 : 2 concrete with 5 per cent of cement replaced with hydrated lime, and the dome is of 1 : 2 : 4 concrete. In order to prevent water from passing through the joints made by each day's work, thin steel bands 4 inches in width were inserted so that one-half of the width was embedded in the old work and one-half in the new.

Examples of Self-densified Concrete Applications

Reinforced Concrete Filter Plant. In the construction of the filter plant at Lancaster, Pa., in 1905, a pure-water basin and several circular tanks were constructed of reinforced concrete. The pure-water basin is 100 feet wide by 200 feet long and 14 feet deep, with buttresses spaced 12 feet 6 inches center to center. The walls at the bottom are 15 inches thick, and 12 inches thick at the top. Four circular tanks are 50 feet in diameter and 10 feet high, and eight

* Engineering Record, December 17, 1910, Vol. 62, No. 25.

† Engineering News, Vol. 75, May 6, 1916.

tanks are 10 feet in diameter and 10 feet high. The walls are 10 inches thick at the bottom and 6 inches at the top. A wet mixture of 1 part cement, 3 parts sand, and 5 parts stone was used. No waterproofing material was used in the construction of the tanks, and when tested, two of them were found to be watertight, the other two had a few leaks where wires, which had been used to hold the forms together, had pulled out when the forms were taken down. These holes were stopped up and no further trouble was experienced. In constructing the floor of the pure-water basin a thin layer of asphalt was used, but no waterproofing material was used in the walls, and both were found to be watertight.

Reinforced Concrete Watertank. A reinforced concrete watertank, 10 feet inside diameter and 43 feet high, designed and constructed by W. B. Fuller at Little Falls, N. J., has some remarkable construction features. It is 15 inches thick at the bottom and 10 inches thick at the top. The tank was built in eight hours, and is a perfect monolith, all concrete being dropped from the top, or 43 feet at the beginning of the work. The concrete was mixed very wet, the mixture being 1 part cement, 3 parts sand, and 7 parts broken stone. No plastering or waterproofing of any kind was used, but the tank was found to be absolutely watertight. The large aggregate was, however, scientifically graded.

Examples of Grouting Applications

Waterproofing Pressure Tunnels. Some of the tunnels of the Catskill Aqueduct of New York City * were made watertight by grouting behind the tunnel lining. This grouting followed the concreting within a period of two to three months, when the concrete had attained sufficient strength to resist high grouting pressures. Air-stirring, grouting machines of the Canniff type, holding about 25 gallons, were generally employed for this work, though a few mechanically stirred Cockburn machines of the same capacity were tried. For low-pressure work, by which the voids about the lining were filled, air direct from the compressor plants was used; for the high-pressure work the air pressure was raised by means of auxiliary high-pressure air compressors.

For filling the voids in the dry packing and the cavities and shrinkage spaces left over the arch concrete, the grout was mixed in the proportion of one cement to one sand, with an equal volume of water, and forced in under pressure of 80 to 100 pounds or more

* Engineering News, Vol. 73, February 4, 1915.

per square inch, depending on the ground-water head. Neat cement was employed in filling the drip pans and other thin cavities. See Fig. 134 for details. No masonry cutoff walls were built to stop the grout, except where dry packing was to be filled, and no attempt was then made to make them tight at the crown of the arch. Work was started at some favorable point where the grout would of itself make a cutoff and carried steadily on, connecting to each pipe in turn. The general practice was to commence grouting through the pipes nearest the invert, and upward to the arch. On completion of the low-pressure grouting, neat-cement grout, generally mixed in the proportion of four to eight volumes of water to one of cement, though sometimes containing as much as fifteen volumes of water to one of cement, was forced into many of the pipes previously grouted and into the deep-seated pipes, under pressures of 250 to 300 pounds per square inch, to fill the small spaces and seams in the rock about the lining. The cost of grouting the tunnels to watertightness ran from $2.50 to $3 per lineal foot of tunnel, including the costs for plant, materials and labor. The tunnel was made remarkably watertight as a result of these operations.

Ashokan Dam Cutoff.* In making watertight the cutoff wall for the Ashokan Dam on the Catskill Aqueduct, a row of 3-inch grouting holes were drilled 20 feet below the bottom of the trench, reaching the greatest depth at which the boring tests had indicated the presence of seams. Similar grouting holes were drilled to about the depth of the cutoff to insure the sealing of any seams that might exist in the rock under the main body of the dam. Two-inch iron pipes were cemented in the tops of the drill holes and carried up into the masonry to permit grouting when the dam had reached sufficient height to withstand the pressure of the grout. These grout pipes were then grouted with neat-cement by the use of a Cockburn Barrow grout machine of 4 cubic feet capacity, operated under a pressure of 25 to 80 pounds. The results were entirely satisfactory.

Rondout Pressure Tunnel. In constructing the Rondout Pressure Tunnel of the Catskill Aqueduct, several wide shafts were sunk. These shafts had to be waterproofed to facilitate operations; especially one shaft in which the seams were large and many. Twenty-seven vertical holes were drilled, 14 to 20 feet deep and capped with pipes and valves for the purpose of grouting these seams. A battery of 4 Canniff tank-grouting machines were set up at the top with $2\frac{1}{2}$-inch pipe in the shaft and a 2-inch hose connection at the bottom. At first the grout leaked back into the shaft in considerable volume.

* "Catskill Water Supply of New York City," by Lazarus White, C. E.

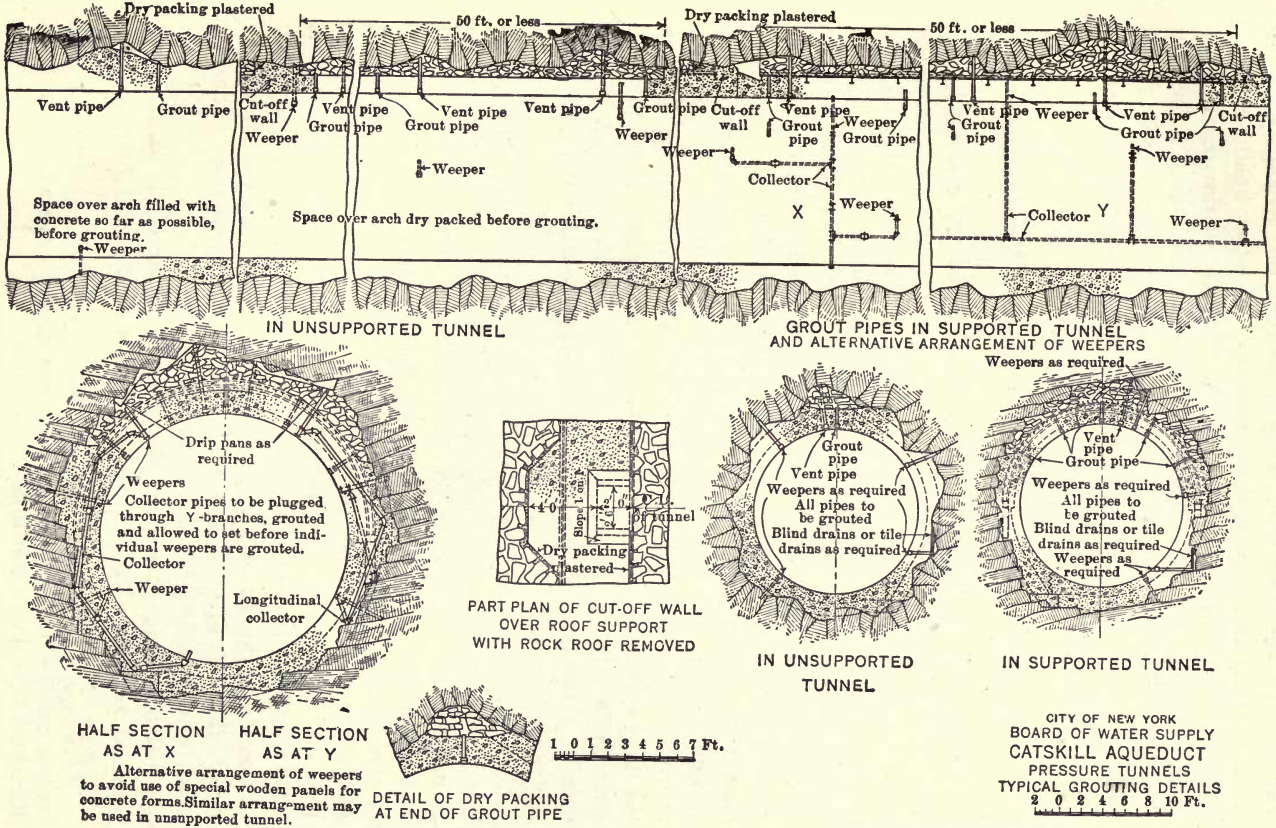


FIG. 134.—Typical Grouting Details Used on Catskill Aqueduct, New York.

Various methods were then tried to prevent this leakage—the use of oats, bran, and ground horse manure, the latter finally clogging the seams and stopping most of the leakage in the shaft. The shallower holes took 2900 bags of cement and the 20-foot holes only 60 bags. This grouting proved to be so successful that it was determined to grout some of the deeper seams known to be porous and water-bearing.

Examples of Special Waterproofing Applications

Harlem River Tunnels. The use of cast-iron, cast-steel, and iron and steel plates for waterproofing is not common but none the less quite practicable. Fig. 135 shows half-sections through the steel lining used as waterproofing for the Harlem River Tunnel tubes connecting the Lexington Avenue subway between Manhattan and Bronx boroughs, forming a part of the Dual Subway System in New York City. The steel (Fig. 135*A*) was sunk in a prepared channel in the river bed and surrounded with concrete within and without. This created an excellent watertight tunnel.* The same is quite true of the cast-iron and cast-steel tunnel linings used on the Pennsylvania railroad tunnels under the Hudson River and the New York Subway tunnels under the East River. See Fig. 136 for details of the type of cast-steel tunnel segments used on the two latter structures.

These segmental linings make an effective waterproofing, though the joints are not absolutely watertight. The leakage, however, is insignificant, as proven by the following fact. In the above-named tunnels, a sump of some form is provided at the lowest point of each tunnel or pair of tunnels and pumped out when necessary by pumps regularly installed. This showed that the daily leakage into the 5½ miles of river tunnels of the Pennsylvania Railroad is 2300 gallons. The magnitude of this may be better appreciated by stating that the entire amount of leakage for one day would be removed in one or two minutes by a pump of the capacity ordinarily used by contractors for foundations.†

Rubber Sheet used on Waterworks Reservoir.‡ A reservoir built in Bellaire, Ohio, in 1905, was put into successful operation

* See paper by Howard B. Gates, "Harlem River Crossing of the Lexington Avenue Subway." The Municipal Engineers Society's Journal, Vol. 1, No. 6, New York City, December, 1915.

† Alfred Noble, in Journal of the Franklin Institute, Vol. 175, p. 383.

‡ Engineering Record, June 3, 1916.

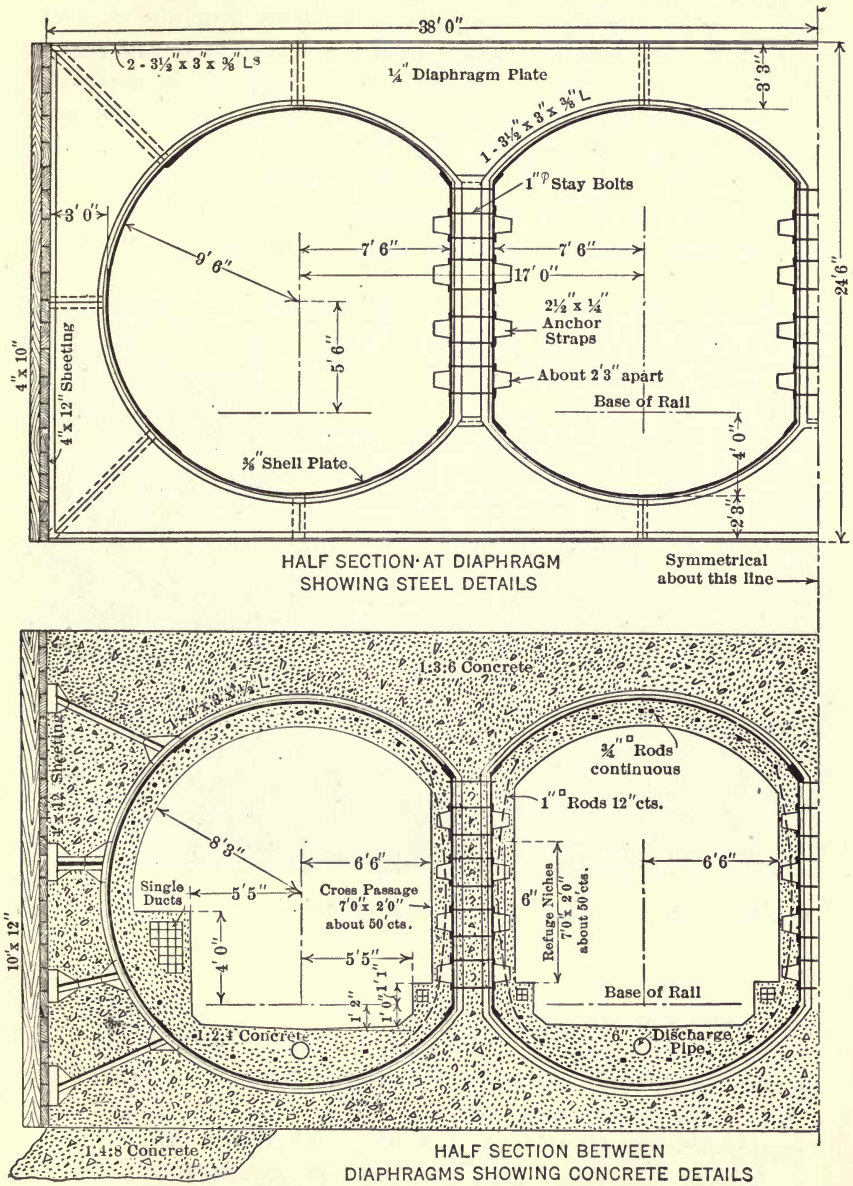


FIG. 135.—Harlem River Tunnel Tubes, as Built.

for the first time in eleven years after its construction. This was made possible only after it was waterproofed by a unique method. Unstable foundations had caused cracks, particularly in one corner of the reservoir, which defied all the many attempts to make the structure watertight until the following inexpensive method was used. A strip of sheet rubber, stretching 30 feet long by 3 feet wide by $\frac{1}{8}$ inch thick, was placed in the corner of the basin covering the crack. A box, built around this rubber-covering and filled with soft mud, kept the sheet in place. Another large crack, in the bottom of the

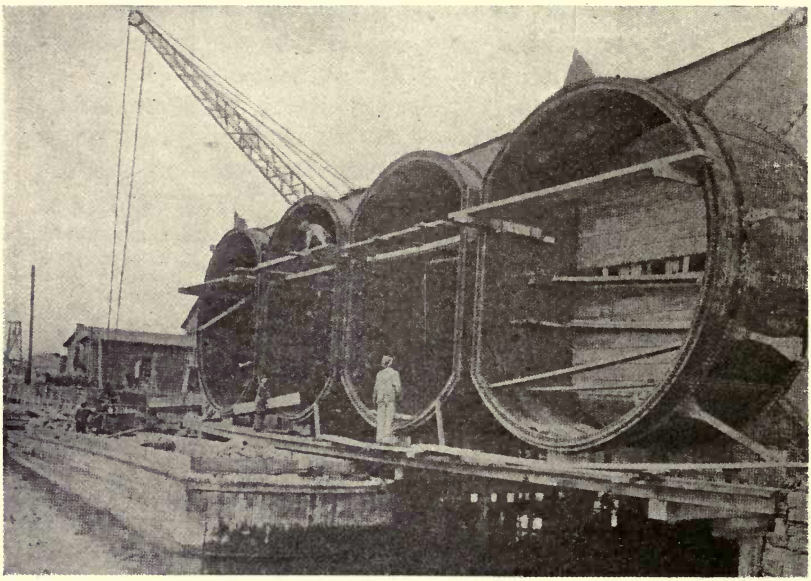


FIG. 135*A*.—Steel Tubes for Harlem River Tunnel, Lexington Avenue Subway, before Sinking.

basin, was also covered with a strip of rubber and held in place by a cement mortar covering. The basin was then filled with water, and it was found that, although the crack in the wall opened $\frac{1}{16}$ inch still further, there was no leakage. This method was suggested and carried into effect by Mr. F. J. Lewis, a resident of Bellaire.

Timber Sheeting Waterproofing for Subaqueous Tunnels.* Referring to Fig. 137, in which timber sheeting constitutes the waterproofing for a subaqueous tunnel, the author believes that if the form of tunnel construction indicated is at all practicable, the

* Proceedings of the American Society of Civil Engineers for November, 1914.

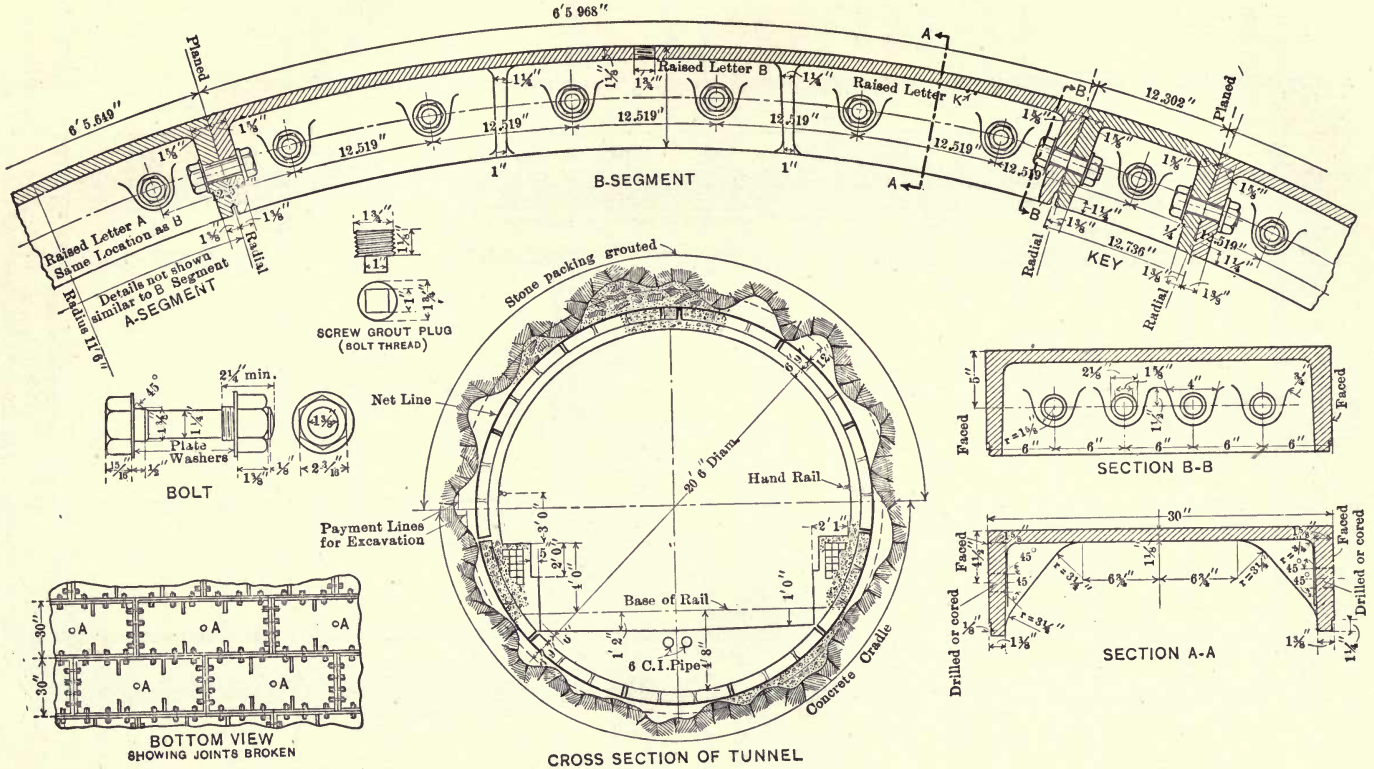


FIG. 136.—Details of Cast-iron Tunnel Segments and Cross-section of a Ring in Place.

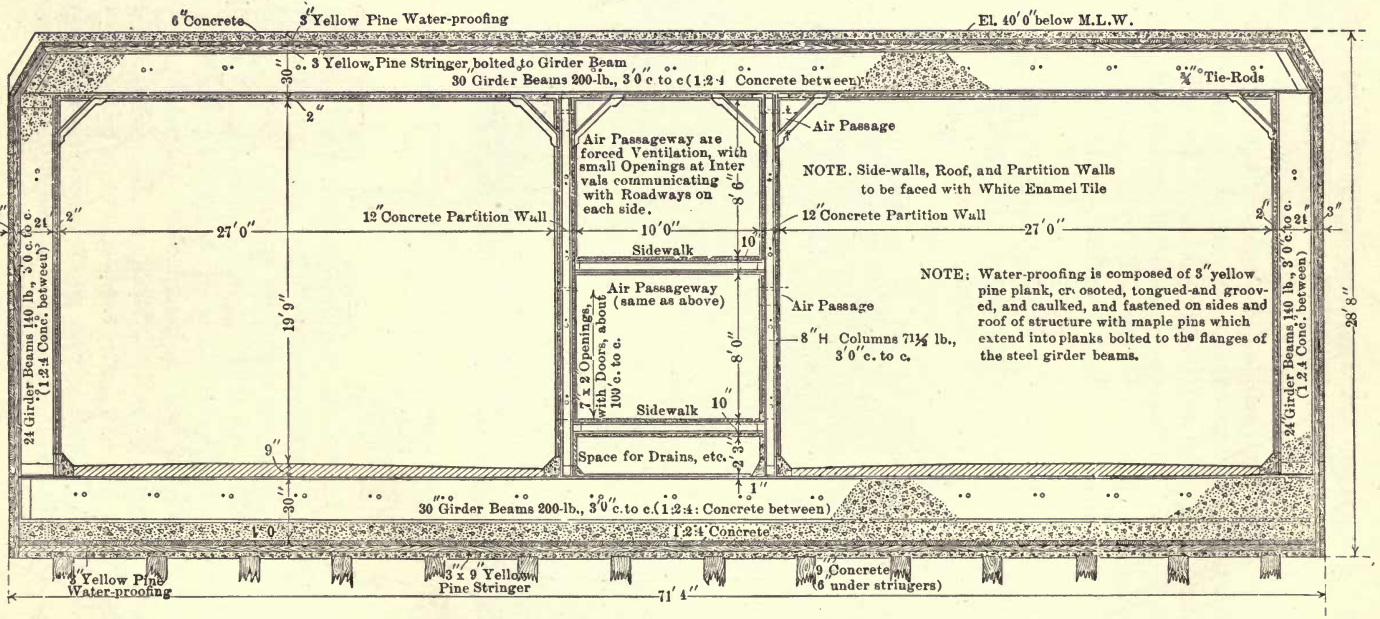


FIG. 137.—Design for Roadway Tunnel under Detroit River, between Detroit, Michigan, and Windsor, Ontario, Showing Timber Sheathing as Water proofing.

proposed waterproofing method seems impracticable. To build a subaqueous tunnel and to waterproof it with creosoted, tongued and grooved yellow pine planking, pinned on the outside of the structural material is a unique conception, though never attempted, to the author's knowledge. This form of waterproofing and its application, Mr. D. D. McBean, the originator, believes will be possible by the use of his patented " Subaqueous Working Chamber " for constructing the tunnel.

Basement Waterproofed with Sheet Lead Lining. The excavation for the basement of the Proctor & Gamble Mfg. Co.'s building on Staten Island, N. Y., was made in red clay. Due to the existence of swampy ground on the site, considerable seepage had to be contended against and prevented from percolating into the cellar. The floor and walls were built of concrete, and were waterproofed by the application on the inside of 1-ply sheet lead weighing 3 pounds per square foot. This sheet lead was also applied to the columns, the strips being carefully soldered together so as to make a seamless pan of the whole. On the floor the sheet lead was laid on a 1-inch sand cushion, and on the wall, directly against the concrete. The entire lead membrane was then protected with a 5-inch layer of concrete. The results obtained by this method of waterproofing were quite satisfactory.

Cement-clay Cover for Hudson and Manhattan Railroad Tunnel. A waterproofing method, in which an impervious layer of cement and clay was interposed between water-bearing ground and a concrete substructure, was used in the recent addition to the Pavonia Avenue station of the Hudson and Manhattan Railroad in Jersey City, N. J. The work consisted in excavating, by tunneling methods and subsequently lining with concrete, a station opening in a water-bearing stratum 200 feet from the Hudson River bulkhead line and 50 feet below mean sea lavel. It was imperative that the concrete lining be watertight, but it had been the experience of the engineers in building the original tunnel that it was impossible in working under air pressure to use any applied waterproofing mats on account of the danger to workmen from fumes; expected expansion and contraction with consequent cracks forbade the use of any integral waterproofing material.

It had been noted that all of the river tunnels which rest in river clay were quite watertight, and it was believed that if a complete coating of clay could be obtained exterior to the tunnel lining, no more nearly perfect or complete waterproofing could be secured. The difficulty with any clay application was that when wet and soft

the clay would change its form by squeezing. Therefore, experiments were made with clay mixed with sufficient Portland cement to hold its form when set.

Hudson River silt, which is a finely pulverized clay with a considerably larger proportion of silica than ordinary clay, was dried and mixed with equal proportions of Portland cement, applied through the medium of a cement gun as a heavy coating on every portion of exposed timbering and lagging in the tunnel. This produced a layer of impervious plaster about 2 inches thick against which the concrete lining of the tunnel was placed. The method has proved successful, the station structure being practically dry under an extreme head of salt water.

Iron-lined Coal Pits.* In constructing concrete coal pits for railway coaling stations of the elevator type it is essential that the pit (for the elevator bucket) should be watertight. The pit is usually considerably below the ground-water level and is subject to pressure, and when once put in operation it is a matter of difficulty and expense to get at it and make repairs.

A plan, which has been used with success, is to place within the concrete a steel boot or tank with joints soldered in the field. A 6-inch thickness of concrete is placed first, and then the steel boot is set in position and the sections soldered. When this has been made watertight it is lined with 6 inches of concrete. All attachments, bolts ladders, etc., are set in this inner lining.

Fig. 138 shows such a pit having a boot 6 feet 11 inches by 11 feet 6 inches and a height of 11 feet, its top being above ground-water level. It is made of No. 20 galvanized iron, and the expectation is that if the metal should rust in course of time it would still form a waterproof diaphragm by combination with the cement. The concrete is a 1 : 5 mix, made with gravel, and mixed moderately wet. The use of a similar boot composed of burlap and asphaltic composition has given fair success. To place a waterproof lining outside of the concrete would involve greater excavation and additional form work.

Calking Tunnels of Pennsylvania Railroad.† In making watertight the East River Tunnels of the Pennsylvania Railroad, the joints between the cast-steel segments composing the tunnel rings were at first calked with a mixture of iron filings and salammoniac in the proportions by weight of 400 to 1. The calking was done by hand.

* Engineering News, Vol. 76, October 5, 1916.

† "The Subways and Tunnels of New York," by G. H. Gilbert, L. I. Wightman and W. L. Saunders.

Later, lead wool, calked cold by pneumatic hammers, was substituted with better results. This calking preceded the placing of a concrete lining about 1 foot thick inside the iron rings. One-to-one grout was then forced between the top of this inner concrete lining and the outer iron segments. Great care was exercised in this work and very good results were obtained.

Waterproofing of the North River Tunnels of the Pennsylvania Railroad consisted in forming a rust joint (with a mixture of sal-

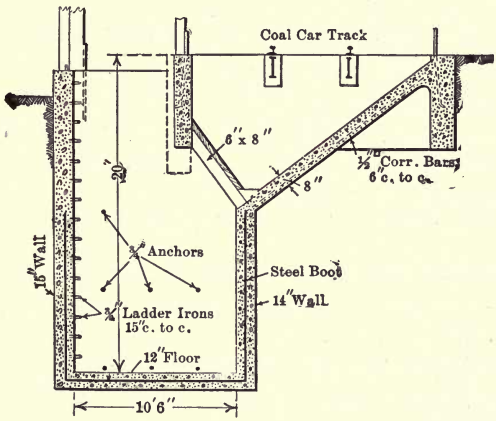


FIG. 138.—Concrete Coal Pit Waterproofed with Sheet Steel Boot.

ammoniac and iron borings) between the plates of the metal lining forming the tubes, and in taking out each bolt and placing around the shank under the washer at each end a grommet made of yarn soaked in red lead. Before calking with the rust mixture the joints were cleaned. The usual mixture for the joints was 2 pounds of salammoniac, 1 pound of sulphur and 250 pounds of iron filings or borings. Air hammers were used with advantage in calking this mixture into the joints. The results were variable and not always satisfactory.

CHAPTER XI

COST DATA ON MATERIALS, IMPLEMENTS, AND LABOR

Planning and Estimating

Importance of Accurate Estimates. Record costs do not always agree with the estimates given for any particular work because analysis for systematizing labor operations preceding the making of such estimates are too often insufficient, or neglected altogether. This is illustrated by the enormous variations in bids received from contractors for the same job. For example, the bids received for waterproofing a section of the New York Dual Subway in 1915 were as follows:

	A.	B.	C.	D.	E.	F.	Maximum Difference (Per cent).
Fabric membrane, 1-ply	$0.50	$0.40	$0.45	$0.35	$0.30	$0.41	66
Fabric membrane, 3-ply	1.00	1.20	1.80	.75	.90	1.10	140
Fabric membrane, 6-ply	2.00	1.60	2.40	1.40	1.50	1.83	71
Brick-in-mastic, cu. yd	25.00	20.00	18.00	22.00	20.00	16.00	56
Protective concrete, cu. yd	7.00	6.50	7.50	6.00	8.00	7.25	33

On another section of the same subway, the following bids for waterproofing work were received:

	A.	B.	C.	D.	E.	Maximum Difference (Per cent).
Fabric membrane, 1-ply	$0.30	$0.35	$0.40	$0.50	$0.60	100
Fabric membrane, 3-ply	.70	1.20	1.10	.90	.80	71
Fabric membrane, 6-ply	1.30	1.50	1.40	2.00	2.25	73
Brick-in-mastic, cu. yd	25.00	29.00	20.00	18.00	....	61
Protective concrete, cu. yd	10.00	7.50	9.00	8.50	8.00	33

To account for such marked differences in estimate figures several items enter into consideration; usually and mainly, these are the result of a wrong estimate of labor cost. The methods of management undoubtedly affect the cost to a very large extent, but this hardly explains the difference of 100 and 140 per cent in the estimated costs submitted by the different contractors. The variations

are more probably due to the following four causes: (1) Inaccurate estimate of volumes or cost of materials; (2) inaccurate estimates of overhead costs and profits; (3) manipulation of estimate prices; (4) inaccurate estimates of labor costs. Material costs usually are figured without difficulty, and these, except during abnormal business conditions, are reasonably constant. Hence, only mistakes are chargeable here. The variation in overhead charges by two different estimators may be large because many contractors do not properly charge or divide their overhead items, but this difference on any one job cannot account for more than 15 or 20 per cent. Manipulation of estimate prices, that is, figuring high on one item and low on another, unless done with great skill and foresight, proves a profitless process so often that it is not generally resorted to. This would, however, in some cases, account for about 50 per cent of the variation. Obviously, then, the big variations must be in the estimated labor cost. And this indeed is the item on which money is usually made or lost in contracting.

Accurate Estimates Dependent on Accurate Methods. Accurate estimates by architects, engineers, and contractors should be made a matter of careful study. An appreciable saving would always result in the substitution of accurate methods for guesswork in estimating. Mr. Sanford E. Thompson, Consulting Engineer,* makes the following remarks in regard to the reduction of general construction costs, which are also applicable to waterproofing costs.

"Accurate cost keeping is of value in following up construction costs from day to day, in showing up waste labor and in providing a mark for the attainment of superintendents and foremen. Unless cost knowledge is in the form of small units, such comparisons cannot be made satisfactorily.

"To get the full benefit of a knowledge of unit costs, and in fact for this the knowledge must be even more thorough and include the unit times of performing the various operations, it must be utilized in the planning of the work in advance and in distributing materials and jobs; in selecting materials and methods which will result in lower labor costs; in adapting the construction plant to the special conditions; and, carried to its ultimate end, in laying out jobs for the workmen and giving them a reward for accomplishment.

"Such management as this involves the adoption of factory methods in construction. Already the need of this is being recognized, but only to a limited degree.

"Full economy in construction, however, will only be attained

* Engineering and Contracting, March 1, 1916, p. 221.

as the builder discards the haphazard rule-of-thumb method and considers his job with a view to thorough analysis, planning functional methods, and a complete study of details. By such methods as these will the labor of construction be brought to a more scientific basis and more nearly on a par with the material end of the work."

Labor and Materials

Waterproofing Labor, Contracters and Manufacturers Graded. Among waterproofing concerns there are to be found the following classes: (1) Waterproofing manufacturers who manufacture and assume responsibility for the quality and effectiveness of the waterproofing material; (2) Manufacturing waterproofers who manufacture and apply the waterproofing material under a guarantee; (3) waterproofing contractors who buy the waterproofing material ready made, supply the labor, and supervise and guarantee the work; (4) waterproofing subcontractors who often are furnished with the waterproofing materials, but always supply the labor, and give personal supervision to the work.

Some of the concerns included under the above classes are not sufficiently responsible or experienced, hence it is often advisable to employ an experienced waterproofing inspector on the work, especially when the magnitude of the work warrants the expense. Where this is not the case, experience has proven the advisability of contracting for the waterproofing work with a reputable and highly responsible waterproofing concern but always under a very specific guarantee.

Many waterproofing concerns maintain laboratories and staffs of engineers who co-operate with the contractor, or builder, in determining the proper system and materials for waterproofing a particular structure. The service is often given gratis. In consequence, the advice, or information, is not always impartial, and it seems advisable that the buyer, builder, architect, or engineer, should investigate somewhat for himself. The result may not only be an improved design but often a reduction in the cost of waterproofing the structure.

The labor employed on waterproofing work is also divided into several classes, as follows: (1) Foremen, who are men generally of large experience in waterproofing work; (2) Waterproofers, men who do the actual waterproofing work, such as laying the brick and mastic courses, sheet mastic, or applying bituminous membranes; (3) helpers, men who help the waterproofers and incidentally learn the trade; (4) Kettlemen, men who tend the kettles in which the bitumen is heated or the mastic is made up; (5) laborers, men who

carry the bricks, wood, etc., to the waterproofers and kettlemen, and perform all the unskilled labor required; (6) roofers, men who mainly waterproof roofs of buildings; (7) roofers' helpers, men who assist the roofers. In none of these divisions is any extraordinary skill required. Indeed, in the application of all waterproofing care and judgment are mostly required.

It is not necessary to employ men of a particular trade to do waterproofing of a particular kind, but it is very essential to employ men with some experience in the particular branch of waterproofing. For example, in waterproofing a structure by the application of a brick-in-mastic envelope, it is not necessary to employ a bricklayer for this purpose, because no special bond of brick, nor refinement of line is required, as in building construction; but experience in handling mastic and properly laying up mastic courses is necessary for good results. This, however, can often be done by the average waterproofer after a short apprenticeship. Besides, the difference in wages between bricklayers and waterproofers would materially affect the contract price of a particular waterproofing job.

The general cost of waterproofing labor depends to a certain extent upon the locality of the work, the nationality of the workmen, but more particularly, of course, upon the character of the work performed.

Cost Data Tables

The cost of most standard waterproofing materials, like other building materials, fluctuates with the market. The cost of patented or special waterproofing materials depends generally on the quantity bought.

In buying waterproofing materials, it should be the aim of those responsible, to buy materials that are either well-known or of proven efficiency because in the end they prove to be the cheapest. Some concerns make a practice of renaming standard materials and selling them at vastly inflated prices. It is no simple matter to guard against this, but when large quantities of waterproofing materials are to be bought, it will pay those concerned to look into the standard materials on the market before buying any special ones. This has particular reference to materials used in the surface coating and integral systems of waterproofing, and joint-filling compounds.

In the following tables will be found the cost of waterproofing materials, labor, and implements for the year 1914. These tables are compiled with more than approximate exactness. Certain other information is included which will be found helpful in estimating and ordering materials. For the duration of the present (1918)

abnormal status of commerce, the cost and price figures given in the tables should be doubled.

Table XXII gives the average wages, during 1914, of the different classes of workers employed in the waterproofing industry and their range includes eastern and western standards of wages. The lower figures usually represent the western scale.

Table XXIII gives the cost and weight of waterproofing implements and tools and some of the manufacturers who specialize in these. The variation and range in cost of each article is mainly due to the difference in size of the articles.

Table XXIV gives the selling price at New York and weight of the most important and most extensively used waterproofing materials. The variation in prices is due to the fact that they include the cost of handling, trucking, etc., except the freight rate, which is too variable.

Table XXV shows the cost of different types of waterproofing applied. The profit to the waterproofer and roofer included in most of these figures ranges between 15 and 30 per cent.

Table XXVI, " Cost of Tin for Flat and Standing Seam Roofing," enables the architect and roofer to calculate the cost of the roofing material from the cheapest to the dearest made tin plate. These prices depend on whether the base plate is iron or steel, and upon the thickness of the coating thereon. The coating consists of an alloy of tin and lead, and the weight of this coating, per box of 112 sheets, is the governing factor in the cost. This weight varies from 8 to 40 pounds. Those plates carrying less than 20 pounds are regarded as the cheaper grade, while those carrying more are in the dearer grade. The weight of coating should be distinctly called for in any tin roofing specification, and also stamped on the tin sheets by the manufacturer.

TABLE XXII.—COST OF WATERPROOFING LABOR
(In 1914)

Class.	Wage Per Eight-hour Day.	Remarks.
Inspector	$4.00 to 5.00	Municipal and private inspection.
Foreman	4.25 to 5.00	On construction work of New York Rapid Transit Subways. Union Labor.
Waterproofers	3.50 to 4.50	
Kettlemen	2.00 to 2.50	
Waterproofers' helpers	1.75 to 2.25	
Laborers	1.50 to 2.00	Unskilled labor.
Roofers	3.50 to 4.50	
Roofers' helpers	2.25 to 2.50	

TABLE XXIII.—COST AND WEIGHT OF VARIOUS WATERPROOFING IMPLEMENTS

Implements.	Cost.	Weight.	Manufacturers.	Remarks.
Broom	$0.25–$0.50	2½–4 lbs.	.....	Cost and weight depend on size of broom corn.
Cutter (steel asphalt)	.....	10 lbs.	Barber Asphalt Paving Co.	Double-edged and tempered.
Cement gun (equipped)	5500.00	6 tons	The Cement Gun Co.	Includes necessary hose, nozzles, air compressor, and engine.
Cement gun (alone)	,1500.00	1500 lbs.	The Cement Gun Co.	Hose, nozzle and minor accessories.
Dipper	1.50–1.75	5–9 lbs.	Barber Asphalt Paving Co., Union Iron Works, Biehl Iron Works.	Made in capacities of 4 to 9 quarts.
Grout mixing machine	175.00	350 lbs.	Ransome Co.	Standard up to 150 lbs. pressure.
Grout mixing machine	250.00	625 lbs.	Ransome Co.	High pressure up to 300 lbs.
Grout mixing machine	350.00	800 lbs.	Ransome Co.	Extra high up to 600 lbs.
Kettle (mastic mixing)	45.00–50.00	.....	Biehl Iron Works, Union Iron Works	Made round in 20–50 gal. capacities; cover included. Cost noted is for large sizes.
Kettle (roofer's heating)	60.00–80.00	310 lbs.	.....	50 gals. All rectangular and of stationary type.
Kettle (roofer's heating)	60.00–80.00	465 lbs.	.....	100 gals. All rectangular and of stationary type.
Kettle (roofer's heating)	60.00–80.00	646 lbs.	.....	150 gals. All rectangular and of stationary type.
Kettle (steam jacketed)	150.00	.....	The Stuart and Paterson Co.	Range from 200–500 gals. capacity, smaller sizes also obtainable. See Fig. 68.
Kettle (portable heating)	.....	350 lbs.	.....	25 gals. (Usual capacity).
Kettle (portable heating)	.....	650 lbs.	.....	50 gals. (Usual capacity).
Mastic mixer (mechanical)	.....	6000 lbs.	Guelich Paving Process Co.	Heated with oil burner and driven by gas engine. See Fig. 67.
Pouring pail	1.00–2.25	.....	Union Iron Works, Biehl Iron Works.	3-gal. capacity and less.
Pouring pail	.....	.....	Biehl Iron Works	3-gal. capacity.
Pouring pail	8.00	.....	Biehl Iron Works	5-gal. capacity (10 in. diam.).
Pouring pail	9.00	.....	Biehl Iron Works	8-gal. capacity (14 in. diam.).
Pouring pail	10.00	.....	Biehl Iron Works	10-gal. capacity (14½ in. diam.).
Salamander 15 in.	4.00–5.00	50 lbs.	G. Drouvé Co.	Prices and weights include covers.
Salamander 20 in.	4.75–5.75	70 lbs.	Biehl Iron Works	Price F. O. B. Factory.
Stirrer	1.50–1.75	12–18 lbs.	Blacksmith or any iron works.	Made in a variety of shapes and sizes.
Smoothers (asphalt)	.....	40 lbs.	.....	10¼×6½ in., 14½×7½ in. Usual sizes.
Scuttle	0.35–0.65	.....	.....	Often used in place of pouring pails.
Shovels	7.50–9.00 (per doz.)	.....	Wyoming Shovel Co.	Square pointed cost more than round.
Tampers (concrete)	.....	.....	Ransome Co.	
Torch (gasoline)	2.50–3.50	4½ lbs.	Ashton Mfg. Co.	1 qt. size. Form and size are the cost factors.
Trowel (steel)	0.25–1.25	.....	.....	Trowels are also made of sheet iron and cost less.
Wheel barrow	3.00–6.00	50–75 lbs.	Sterling Wheelbarrow Co.	Cost and weight depend on gauge of steel.
Mops (yarn)	0.30–0.40	1½ lbs.	.....	Skeins of yarn bought at 15 cents per lb. and attached to wooden handles. Make-up mops.
Brick heater (iron)	75.00–100.00	.....	Any iron works or blacksmith.	About 4×4×8 ft. high with flat pan salamander.
Electric oven	75.00	.....	Frea's Apparatus Co.	Size of heating chamber 12×12×12 in.
Barrels (double headed)	1.65	70–75 lbs.	.....	Production cost (without profit), approx. 52 gal. cap.
Barrels (slack)*	0.40	10–15 lbs.	.....	Production cost (without profit), approx. 36 gal. cap.
Cord wood	6.00–8.00	1¾–2 tons	.....	Used for fire-heated kettles.
Wood cores	38.00–40.00 per M. ft. Bm.	1–1½ tons	.....	Cores (2×2×36 in. and 2×2×42 in.) inserted in felt and fabric rolls to maintain their form.

* Slack or lime barrels have been standardized by an act of Congress (Aug., 1916). Two sizes are specified, one to contain 180 lbs. and the other 280 lbs. net.

TABLE XXIV.—COST AND WEIGHT OF VARIOUS WATERPROOFING MATERIALS (1914)

Material.	Weight.	Cost.	Measure.	Remarks.
Asphalt (refined)	64– 68 lb. per cu. ft.	$14.00–$19.00	per ton	Competition and grade of asphalt greatly affect the cost.
Fabric (asphalt treated)	12– 16 lb. per square*	0.95– 1.25	per square*	7½ oz. open mesh jute fabric.
Felt (asphalt treated)	40– 56 lb. per roll	1.00– 1.25	per square	Numerous weights of felt made; price depends largely on weight. Width 36 ins., 4 squares per roll.
Alum	107–115 lb. per cu. ft.	0.18– 0.23	per lb	
Asbestos	175–192 lb. per cu. ft.	0.50– 0.60	per lb	Used in shredded form; cost is governed by length and purity of shreds.
Benzine	6.25–6.5 lb. per gal	0.18– 0.21	per gal	In bbl. lots.
Bricks	115–150 lb. per cu. ft.	6.00– 8.50	per thousand	Common red building brick; cost includes cartage in New York.
Stone (broken)	90–110 lb. per cu. ft.	0.80– 1.15	per cu. yd.	¾-inch size (used for protective concrete) alongside of New York River Docks.
Caustic potash		0.06– 0.16	per lb	Cost depends on grade.
Coal-tar pitch	74– 78 lb. per cu. ft.	14.00– 16.00	per ton	Straight-run coal-tar product.
Felt (coal-tar treated)	50– 55 lb. per roll	63.00	per ton	432 sq. ft. per roll. Cheap and medium grade included. Single ply.
Felt (coal-tar treated)	60 lb. per roll	78.00	per ton	432 sq. ft. per roll. Best grade. Single ply.
Felt (coal-tar treated)	40– 50 lb. per roll	0.78– 0.88	per roll	100 sq. ft. per roll. Two ply, medium and heavy grades.
Felt (coal-tar treated)	60– 70 lb. per roll	1.13– 1.23	per roll	100 sq. ft. per roll. Three ply, medium and heavy grades.
Concrete	125–160 lb. per cu. ft.	5.00– 7.50	per cu. yd.	Protective concrete; usually laid 4 ins. thick.
Gasoline	5.65 lb. per gal	0.20– 0.24	per gal	In bbl. lots.
Gilsonite	66.5 lb. per cu. ft.	36.00– 50.00	per ton	

Graphite	140 lb. per cu. ft.	0.01½– 0.03 per lb.	Price dependent on percentage of carbon present.
Gravel	105–120 lb. per cu. ft.	0.95– 1.15 per cu. yd.	Alongside of New York River Docks.
Iron (filings, drillings or powder)	440–460 lb. per cu. ft.	0.01–0.02 per lb.	Made of cast iron, oil free. Comes separately graded from fine to moderately coarse.
Hydrated lime	36– 45 lb. per sq. ft.	6.50– 7.00 per bbl.	
Lime (common)	50– 60 lb. per cu. ft.	1.15– 1.40 per bbl.	
Limestone dust	70– 80 lb. per cu. ft.	3.00– 4.00 per ton	10 cents rebate for return of empty bags.
Lead wool	650 lb. per cu. ft.	0.13– 0.18 per lb.	For calking all manner of steel joints.
Linseed oil	7¾ lb. per gal.	0.55– 0.65 per gal.	
Cement (natural)	75– 85 lb. per cu. ft.	0.90– 1.15 per bbl.	Shipped in bags (four of which equal 1 bbl.) 10 cents rebate allowed on return of each bag.
Fabric (oil-tar pitch treated)	14– 18 lb. per square.	0.95– 1.15 per square*	7½ oz. open mesh jute fabric.
Oil-tar pitch	72– 76 lb. per cu. ft.	12.00– 13.00 per ton	Mainly used for roofing, with felt.
Paraffin (solid)	.55 lb. per cu. ft.	4.80 per cwt.	In crude form.
Paraffin oil	56 lb. per cu. ft.	0.13– 0.14 per gal.	
Cement (Portland)	100–110 lb. per cu. ft.	1.30– 1.67 per bbl.	Shipped in bags (four of which equal 1 bbl.) 10 cents rebate on return of each bag.
Burlap (jute)	7– 8 oz. per sq. yd.	0.05– 0.07 per sq. yd.	Open mesh variety.
Burlap (paper)	.....	.....	Open mesh variety.
Cotton drill	4– 6 oz. per sq. yd.	0.08– 0.12 per sq. yd.	Close mesh woven cotton fabric varying in thread count from 32×34 to 66×68.
Soap (castile)	70– 80 lb. per cu. ft.	0.12– 0.15 per lb.	Cudahy's Genoa brand.
Sawdust	.....	11.00 per ton	This is a much finer grade than used for ordinary purposes. Made of pine or cedar.
Sand	80– 90 lb. per cu. ft.	1.00– 1.50 per cu. yd.	Loose; delivered at New York River Docks.
Turpentine	7¼ lb. per gal.	0.20– 0.22 per gal.	In bbl. lots.
Wood flour	.....	25.00 per ton	Very finely pulverized and pulpy; made of pine or cedar.

* One square consists of 100 sq. ft., but in practice 5 to 8 ft. extra are usually included for lapping.

TABLE XXV.—COST OF WATERPROOFING APPLIED

Type of Structure Waterproofed.	System of Waterproofing.	Materials Employed.	No. of Plies or Quantities.	Manner of Application.	Cost.	Unit.	Remarks.
Bridge floors	Membrane	Saturated felt and coal-tar pitch binder	6 plies	In alternate layers	$1.12½	Per sq. yd.	Includes protective masonry over waterproofing.
Bridge floors	Membrane	Burlap, asphalt, and asphalt mastic	3 plies and ½ in. of mastic	Burlap and asphalt in alternate layers, mastic on top	1.44	Per sq. yd.	Untreated burlap used.
Bridge floors	Membrane	Saturated felt, burlap and pitch binder	5 plies felt and 1 ply burlap	Felt and pitch in alternate layers. Burlap in center of membrane	1.40	Per sq. yd.	Includes a ten-yr. guarantee.
Bridge floors	Membrane	Burlap and asphalt binder	4 plies	In alternate layers	0.90–1.48	Per sq. yd.	Untreated burlap used.
Brick wall	Surface coating	Alum and soap	4 coats	Brushed on in alternate coats as a paint	54–.90	Per sq. yd.	
Concrete water storage tank	Surface coating	Paraffin	1 coat	Applied and rubbed in with a brush	.18–.36	Per sq. yd., per coat	Labor and material only.
Concrete dam	Surface coating	1 : 2 mortar	Coat 1-in. thick.	With cement gun	.72	Per sq. yd.	Applied in 2 layers.
Concrete tanks, conduits, masonry walls	Surface coating	Alum and soap	4 coats	In alternate coats applied as a paint	.04½–.36	Per sq. yd.	Applicable to new or old work but not underground.
Concrete walls	Surface coating	Paraffin wax	1 coat	Melted and applied hot as a paint	.45–.72	Per sq. yd.	
Foundation walls	Membrane	Treated cotton fabric and asphalt binder	3 plies	In alternate layers	1.00–1.35	Per sq. yd.	Contract price.
Subway roof and walls	Membrane	Treated jute fabric and coal-tar pitch binder	1 ply	In alternate layers	.40*	Per sq. yd.	Average of 19 bids on Dual Subway System of N. Y. C. Contract prices.
Subway roof and walls	Membrane	Treated jute fabric and coal-tar pitch binder	2 plies	In alternate layers	.70*	Per sq. yd.	Average of 19 bids on Dual Subway System of N. Y. C. Contract prices.
Subway roof and walls	Membrane	Treated jute fabric and coal-tar pitch binder	3 plies	In alternate layers	.95*	Per sq. yd.	Average of 19 bids on Dual Subway System of N. Y. C. Contract prices.
Subway roof and walls	Membrane	Treated jute fabric and coal-tar pitch binder	4 plies	In alternate layers	1.27	Per sq. yd.	Average of 19 bids on Dual Subway System of N. Y. C. Contract prices.

* Actual cost of material and labor, applied, for 1-, 2-, and 3-ply was 26, 44, and 61 cents, respectively.

TABLE XXV.—COST OF WATERPROOFING APPLIED—*Continued*

Type of Structure Waterproofed.	System of Waterproofing.	Materials Employed.	No. of Plies or Quantities.	Manner of Application.	Cost.	Unit.	Remarks.
Subway roof and walls	Membrane.....	Treated jute fabric and coal-tar pitch binder	5 plies.....	In alternate layers....	$1.57	Per sq. yd.	Average of 19 bids on Dual Subway System of N. Y. C. Contract prices.
Subway roof and walls	Membrane.....	Treated jute fabric and coal-tar pitch binder	6 plies.....	In alternate layers....	1.92	Per sq. yd.	Average of 19 bids on Dual Subway System of N. Y. C. Contract prices.
Subway roof and walls	Membrane.....	Treated felt with asphalt or pitch binder	1 ply.....	Binder applied only to upper surface of felt	.34	Per sq. yd.	Used as dry ply on moist surface.
Subway roof and walls	Mastic	Brick and asphalt mastic	2 courses.....	Brick embedded in mastic	22.01*	Per cu. yd.	Average of 19 bids on Dual Subway System of N. Y. C. Contract prices.
Roof of building.....	Membrane.....	Tar treated felt, asphalt and slag	5 plies.....	Felt and asphalt in alternate layers. Covered with slag	.50–.60	Per sq. yd.	Applicable to both board and concrete roofs.
Roof of building.....	Shingle roof....	Slate shingles.....	.....	Laid to overlap.....	.90	Per sq. yd.	Cost varies with area of shingles exposed to weather and kind of slate used.
Roof of building.....	Shingle roof....	Asbestos shingles.....	.....	Laid to overlap	1.44	Per sq. yd.	Cost varies with area of shingles exposed to weather and kind of asbestos used.
Roof of building.....	Shingle roof....	Wood shingles.	.....	Laid to overlap.	.45–.63	Per sq. yd.	Cost varies with area of shingles exposed to weather and kind of wood used.
Roof of building.....	Ready roofing..	Asphalt treated felt...	1 ply.....	Applied with lap joints and nailed to roof boards.	.27–.34	Per sq. yd.	Guaranteed for five years.
Roof of building	Membrane.....	Treated felt, coal-tar pitch and gravel	5 plies	Felt and pitch in alternate layers, gravel on top	3.75–4.00	Per square†	Over board sheathing under average conditions.

* Actual cost of material and labor, for 2 courses, applied, was $16.00.
† One square contains 100 sq. feet.

TABLE XXVI.—COST OF TIN FOR FLAT AND STANDING SEAM ROOFING *

Tin Plates 14 by 20.			Tin Plates 20 by 28.		
When Tin Costs (per Box.)	Flat Seam (Cost per Square).	Standing Seam (Cost per Square).	When Tin Costs (per Box).	Flat Seam (Cost per Square).	Standing Seam (Cost per Square).
$3.00	$1.67	$1.85	$6.00	$1.57	$1.69
4.00	2.22	2.47	8.00	2.10	2.25
5.00	2.78	3.09	10.00	2.62	2.81
6.00	3.34	3.71	12.00	3.15	3.37
7.00	3.89	4.32	14.00	3.67	3.94
8.00	4.45	4.94	16.00	4.20	4.50
9.00	5.00	5.56	18.00	4.72	5.06
10.00	5.56	6.18	20.00	5.25	5.62
11.00	6.11	6.80	22.00	5.77	6.19
12.00	6.67	7.41	24.00	6.30	6.75

*Price per 100 square feet at a given price per box of 112 sheets—Cost of laying not included.

CHAPTER XII

PRACTICAL TABLES

Explanation of Tables. Tables are very useful, and in technical books indispensable, especially when they are all pertinent to the subject. A conscientious effort has been made to keep the present work free of the encumbrance of irrelevant tables. The few included herein have been found indispensable. They are believed to be accurate but not necessarily complete, though sufficient for all practical purposes.

Table XXVII, "Thermometric Equivalents," converts the Fahrenheit temperature scale into the Centigrade scale and vice versa. This is often necessary in the laboratory and in the field.

Table XXVIII gives the relative values of density and specific gravity of liquids heavier than water.

Table XXIX, "Specific Gravity and Baumé for Liquids Lighter than Water," shows the relation of density, as recorded on the Baumé scale, to specific gravity of liquids lighter than water. Every liquid lighter than water has a definite specific gravity at a certain temperature, and in consequence a definite density which is usually measured by the hydrometer and expressed on the Baumé scale. Some liquids, such as petroleum oils, when distilled at and to a certain temperature, give off volatile oils, which leave the residue denser than the original; this denser composition is indicated by a correspondingly higher reading on the Baumé scale. This reading may be transformed, by means of the table, into an equivalent specific gravity of that liquid for that temperature.

Table XXX, "Specific Gravity and Coefficient of Expansion of Various Materials," is compiled from the most reliable sources. Some of the values are not to be found in any book, having been obtained from research laboratory tests. A knowledge of the relative expansion and contraction of mineral and organic solids and liquids is often necessary in waterproofing engineering.

Table XXXI, "Weight and Thickness of Burlap, Felt, and Cotton Fabric Membranes with Coal-tar Pitch Binder," is based on waterproofing membranes made only with coal-tar pitch binder. If

TABLE XXVII.—THERMOMETRIC EQUIVALENTS

(CENTIGRADE AND FAHRENHEIT)

C.°	F.°	C.°	F.°	C.°	F.°	C.°	F °	C.°	F.°	C.°	F °	C.°	F.°	C.°	F.°	C.°	F.°
−29	−20.2	0	32	35	95	71	159.8	107	224.6	143	289.4	179	354.2	214	417.2	247	476.6
28	18.4	+1	33.8	36	96.8	72	161.6	108	226.4	144	291.2	180	356.2	215	419	248	478.4
27	.16.6	2	35.6	37	98.6	73	163.4	109	228.2	145	293	181	357.8	216	420.8	248.9	480
26	14.8	3	37.4	38	100.4	74	165.2	110	230	146	294.8	182	359.6	217	422.6	249	480.2
25	13.0	4	39.2	39	102.2	75	167	111	231.8	147	296.6	183	361.4	218	424.4	250	482
24	11.2	5	41	40	104	76	168.8	112	233.6	148	298.4	184	363.2	218.3	425	251	483.8
23	9.4	6	42.8	41	105.8	77	170.6	113	235.4	149	300.2	185	365	219	426.2	252	485.6
22	7.6	7	44.6	42	107.6	78	172.4	114	237.2	150	302	186	366.8	220	428	253	487.4
21	5.8	8	46.4	43	109.4	79	174.2	115	239	151	303.8	187	368.6	221	429.8	254	489.2
20	4.0	9	48.2	44	111.1	80	176	116	240.8	152	305.6	188	370.4	222	431.6	255	491
19	2.2	10	50	45	113	81	177.8	117	242.6	153	307.4	189	373.2	223	433.4	256	492.8
18	0.4	11	51.8	46	114.8	82	179.6	118	244.4	154	309.2	190	374	224	435.2	257	494.6
17	+1.4	12	53.6	47	116.6	83	181.4	119	246.2	155	311	191	375.8	225	437	258	496.4
16	3.2	13	55.4	48	118.4	84	183.2	120	248	156	312.8	192	377.6	226	438.8	259	498.2
15	5.0	14	57.2	49	120.2	85	185	121	249.8	157	314.6	193	379.4	227	440.6	260	500
14	6.8	15	59	50	122	86	186.8	122	251.6	158	316.4	194	381.2	228	442.4	261	501.8
13	8.6	15.5	60	51	123.8	87	188.6	123	253.4	159	318.2	195	383	229	444.2	262	503.6
12	10.4	16	60.8	52	125.6	88	190.4	124	255.2	160	320	196	384.8	230	446	263	505.4
11	12.2	17	62.6	53	127.4	89	192.2	125	257	161	321.8	197	386.6	231	447.8	264	507.2
10	14.0	18	64.4	54	129.2	90	194	126	258.8	162	323.6	198	388.4	232	449.6	265	509
9	15.8	19	66.2	55	131	91	195.8	127	260.6	163	325.4	199	390.2	232.1	450	266	510.8
8	17.6	20	68	56	132.8	92	197.6	128	262.4	164	327.2	200	392	233	451.4	267	512.6
7	19.4	21	69.8	57	134.6	93	199.4	129	264.2	165	329	201	393.8	234	453.2	268	514.4
6	21.2	22	71.6	58	136.4	94	201.2	130	266	166	330.8	202	395.6	235	455	269	516.2
5	23.0	23	73.4	59	138.2	95	203	131	267.8	167	332.6	203	397.4	236	456.8	270	518
4	24.8	24	75.2	60	140	96	204.8	132	269.6	168	334.4	204	399.2	237	458.6	271	519.8
3	26.6	25	77	61	141.8	97	206.6	133	271.4	169	336.2	204.4	400	238	460.4	272	521.6
2	28.4	26	78.8	62	143.6	98	208.4	134	273.2	170	338	205	401	239	462.2	273	523.4
1	30.2	27	80.6	63	145.4	99	210.2	135	275	171	339.7	206	402.8	240	464	274	525.2
.....	.....	28	82.4	64	147.2	100	212	136	276.8	172	341.6	207	404.6	241	465.8	275	527
.....	.....	29	84.2	65	149	101	213.8	137	278.6	173	343.4	208	406.4	242	467.6	276	528.8
.....	.....	30	86	66	150.8	102	215.6	138	280.4	174	345.2	209	408.2	243	469.4	277	530.6
.....	.....	31	87.8	67	152.6	103	217.4	139	282.2	175	347	210	410	244	471.2	278	532.4
.....	.....	32	89.6	68	154.4	104	219.2	140	284	176	348.8	211	411.8	245	473	279	534.2
.....	.....	33	91.4	69	156.2	105	221.1	141	285.8	177	350.6	212	413.6	246	474.8	280	536
.....	.....	34	93.2	70	158	106	222.8	142	287.6	178	352.4	213	415.4	246.1	475	287.8	550

TABLE XXVIII

Specific Gravities at $\frac{60°}{60°}$ F. $\left[\frac{15°.56}{15°.56}\text{C.}\right]$ Corresponding to Degrees Baumé for Liquids Heavier than Water

$\left[\text{Calculated from the formula, specific gravity } \frac{60°}{60°}\text{F.} = \frac{145}{145 - \text{Deg. Baumé}}\right]$

Degrees Baumé.	Tenths of Degrees Baumé.									
	0	1	2	3	4	5	6	7	8	9
0	1.0000	1.0007	1.0014	1.0021	1.0028	1.0035	1.0042	1.0049	1.0055	1.0062
1	1.0069	1.0076	1.0083	1.0090	1.0097	1.0105	1.0112	1.0119	1.0126	1.0133
2	1.0140	1.0147	1.0154	1.0161	1.0168	1.0175	1.0183	1.0190	1.0197	1.0204
3	1.0211	1.0218	1.0226	1.0233	1.0240	1.0247	1.0255	1.0262	1.0269	1.0276
4	1.0284	1.0291	1.0298	1.0306	1.0313	1.0320	1.0328	1.0335	1.0342	1.0350
5	1.0357	1.0365	1.0372	1.0379	1.0387	1.0394	1.0402	1.0409	1.0417	1.0424
6	1.0432	1.0439	1.0447	1.0454	1.0462	1.0469	1.0477	1.0484	1.0492	1.0500
7	1.0507	1.0515	1.0522	1.0530	1.0538	1.0545	1.0553	1.0561	1.0569	1.0576
8	1.0584	1.0592	1.0599	1.0607	1.0615	1.0623	1.0630	1.0638	1.0646	1.0654
9	1.0662	1.0670	1.0677	1.0685	1.0693	1.0701	1.0709	1.0717	1.0725	1.0733
10	1.0741	1.0749	1.0757	1.0765	1.0773	1.0781	1.0789	1.0797	1.0805	1.0813
11	1.0821	1.0829	1.0837	1.0845	1.0853	1.0861	1.0870	1.0878	1.0886	1.0894
12	1.0902	1.0910	1.0919	1.0927	1.0935	1.0943	1.0952	1.0960	1.0968	1.0977
13	1.0985	1.0993	1.1002	1.1010	1.1018	1.1027	1.1035	1.1043	1.1052	1.1060
14	1.1069	1.1077	1.1086	1.1094	1.1103	1.1111	1.1120	1.1128	1.1137	1.1145
15	1.1154	1.1162	1.1171	1.1180	1.1188	1.1197	1.1206	1.1214	1.1223	1.1232
16	1.1240	1.1249	1.1258	1.1267	1.1271	1.1284	1.1293	1.1302	1.1310	1.1319
17	1.1328	1.1337	1.1346	1.1355	1.1364	1.1373	1.1381	1.1390	1.1399	1.1408
18	1.1417	1.1426	1.1435	1.1444	1.1453	1.1462	1.1472	1.1481	1.1490	1.1499
19	1.1508	1.1517	1.1526	1.1535	1.1545	1.1554	1.1563	1.1572	1.1581	1.1591
20	1.1600	1.1609	1.1619	1.1628	1.1637	1.1647	1.1656	1.1665	1.1675	1.1684
21	1.1694	1.1703	1.1712	1.1722	1.1731	1.1741	1.1750	1.1760	1.1769	1.1779
22	1.1789	1.1798	1.1808	1.1817	1.1827	1.1837	1.1846	1.1856	1.1866	1.1876
23	1.1885	1.1958	1.1905	1.1915	1.1924	1.1934	1.1944	1.1954	1.1964	1.1974
24	1.1983	1.1993	1.2003	1.2013	1.2023	1.2033	1.2043	1.2053	1.2063	1.2073
25	1.2083	1.2093	1.2104	1.2114	1.2124	1.2134	1.2144	1.2154	1.2164	1.2175
26	1.2185	1.2195	1.2205	1.2216	1.2226	1.2236	1.2247	1.2257	1.2267	1.2278
27	1.2288	1.2299	1.2309	1.2319	1.2330	1.2340	1.2351	1.2361	1.2372	1.2383
28	1.2393	1.2404	1.2414	1.2425	1.2436	1.2446	1.2457	1.2468	1.2478	1.2489
29	1.2500	1.2511	1.2522	1.2532	1.2543	1.2554	1.2565	1.2576	1.2587	1.2598
30	1.2609	1.2620	1.2631	1.2642	1.2653	1.2664	1.2675	1.2686	1.2697	1.2708
31	1.2719	1.2730	1.2742	1.2753	1.2764	1.2775	1.2787	1.2798	1.2809	1.2821
32	1.2832	1.2843	1.2855	1.2866	1.2877	1.2889	1.2900	1.2912	1.2923	1.2935
33	1.2946	1.2958	1.2970	1.2981	1.2993	1.3004	1.3016	1.3028	1.3040	1.3051
34	1.3063	1.3075	1.3087	1.3098	1.3110	1.3122	1.3134	1.3146	1.3158	1.3170
35	1.3182	1.3194	1.3206	1.3218	1.3230	1 3242	1.3254	1.3266	1.3278	1.3291

TABLE XXVIII.—*Continued*

Specific Gravities at $\frac{60°}{60°}$ F. $\left[\frac{15°.56}{15°.56}\text{C.}\right]$ Corresponding to Degrees Baumé for Liquids Heavier than Water

Degrees Baumé.	Tenths of Degrees Baumé.									
	0	1	2	3	4	5	6	7	8	9
36	1.3303	1.3315	1.3327	1.3339	1.3352	1.3364	1.3376	1.3389	1.3401	1.3414
37	1.3426	1.3438	1.3451	1.3463	1.3476	1.3488	1.3501	1.3514	1.3526	1.3539
38	1.3551	1.3564	1.3577	1.3590	1.3602	1.3615	1.3628	1.3641	1.3653	1.3666
39	1.3679	1.3692	1.3705	1.3718	1.3731	1.3744	1.3757	1.3770	1.3783	1.3796
40	1.3810	1.3823	1.3836	1.3849	1.3862	1.3876	1.3889	1.3902	1.3916	1.3929
41	1.3942	1.3956	1.3969	1.3983	1.3996	1.4010	1.4023	1.4031	1.4050	1.4064
42	1.4078	1.4091	1.4105	1.4119	1.4133	1.4146	1.4160	1.4174	1.4188	1.4202
43	1.4216	1.4230	1.4244	1.4258	1.4272	1.4286	1.4300	1.4314	1.4328	1.4342
44	1.4356	1.4371	1.4385	1.4399	1.4414	1.4428	1.4442	1.4457	1.4471	1.4486
45	1.4500	1.4515	1.4529	1.4544	1.4558	1.4573	1.4588	1.4602	1.4617	1.4632
46	1.4646	1.4661	1.4676	1.4691	1.4706	1.4721	1.4736	1.4751	1.4766	1.4781
47	1.4796	1.4811	1.4826	1.4841	1.4857	1.4872	1.4887	1.4902	1.4918	1.4933
48	1.4948	1.4964	1.4979	1.4995	1.5010	1.5026	1.5041	1.5057	1.5073	1.5088
49	1.5104	1.5120	1.5136	1.5152	1.5167	1.5183	1.5199	1.5215	1.5231	1.5247
50	1.5263	1.5279	1.5295	1.5312	1.5328	1.5344	1.5360	1.5376	1.5393	1.5409
51	1.5426	1.5442	1.5458	1.5475	1.5491	1.5508	1.5525	1.5541	1.5558	1.5575
52	1.5591	1.5608	1.5625	1.5642	1.5659	1.5676	1.5693	1.5710	1.5727	1.5744
53	1.5761	1.5778	1.5795	1.5812	1.5830	1.5847	1.5864	1.5882	1.5889	1.5917
54	1.5934	1.5952	1.5969	1.5987	1.6004	1.6022	1.6040	1.6058	1.6075	1.6093
55	1.6111	1.6129	1.6147	1.6165	1.6183	1.6201	1.6219	1.6237	1.6256	1.6274
56	1.6292	1.6310	1.6329	1.6347	1.6366	1.6384	1.6403	1.6421	1.6440	1.6459
57	1.6477	1.6496	1.6515	1.6534	1.6553	1.6571	1.6590	1.6609	1.6628	1.6648
58	1.6667	1.6686	1.6705	1.6724	1.6744	1.6763	1.6782	1.6802	1.6821	1.6841
59	1.6860	1.6880	1.6900	1.6919	1.6939	1.6959	1.6979	1.6999	1.7019	1.7039
60	1.7059	1.7079	1.7099	1.7119	1.7139	1.7160	1.7180	1.7200	1.7221	1.7241
61	1.7262	1.7282	1.7303	1.7324	1.7344	1.7365	1.7386	1.7407	1.7428	1.7449
62	1.7470	1.7491	1.7512	1.7533	1.7554	1.7576	1.7597	1.7618	1.7640	1.7661
63	1.7683	1.7705	1.7726	1.7748	1.7770	1.7791	1.7813	1.7835	1.7857	1.7879
64	1.7901	1.7923	1.7946	1.7968	1.7990	1.8012	1.8035	1.8057	1.8080	1.8102
65	1.8125	1.8148	1.8170	1.8193	1.8216	1.8239	1.8262	1.8285	1.8308	1.8331
66	1.8354	1.8378	1.8401	1.8424	1.8448	1.8471	1.8495	1.8519	1.8542	1.8566
67	1.8590	1.8614	1.8638	1.8662	1.8686	1.8710	1.8734	1.8758	1.8782	1.8807
68	1.8831	1.8856	1.8880	1.8905	1.8930	1.8954	1.8979	1.9004	1.9029	1.9054
69	1.9079	1.9104	1.9129	1.9155	1.9180	1.9205	1.9231	1.9256	1.9282	1.9308
70	1.9333									

TABLE XXIX

Specific Gravities at $\frac{60°}{60°}$ F. $\left[\frac{15°.56}{15°.56}\text{C.}\right]$ Corresponding to Degrees Baumé for Liquids Lighter than Water

$\left[\text{Calculated from the formula, specific gravity } \frac{60°}{60°}\text{F.} = \frac{140}{130+\text{Deg. Baumé}}\right]$

Degrees Baume.	Tenths of Degrees Baumé.									
	0	1	2	3	4	5	6	7	8	9
10	1.0000	0.9993	0.9986	0.9979	0.9972	0.9964	0.9957	0.9950	0.9943	0.9936
11	.9929	.9922	.9915	.9908	.9901	.9894	.9887	.9880	.9873	.9866
12	.9859	.9852	.9845	.9838	.9831	.9825	.9818	.9811	.9804	.9797
13	.9790	.9783	.9777	.9770	.9763	.9756	.9749	.9743	.9736	.9729
14	.9722	.9715	.9709	.9702	.9695	.9689	.9682	.9675	.9669	.9662
15	.9655	.9649	.9642	.9635	.9629	.9622	.9615	.9609	.9602	.9596
16	.9589	.9582	.9576	.9569	.9563	.9556	.9550	.9543	.9537	.9530
17	.9524	.9517	.9511	.9504	.9498	.9492	.9485	.9479	.9472	.9466
18	.9459	.9453	.9447	.9440	.9434	.9428	.9421	.9415	.9409	.9402
19	.9396	.9390	.9383	.9377	.9371	.9365	.9358	.9352	.9346	.9340
20	.9333	.9327	.9321	.9315	.9309	.9302	.9296	.9290	.9284	.9278
21	.9272	.9265	.9259	.9253	.9247	.9241	.9235	.9229	.9223	.9217
22	.9211	.9204	.9198	.9192	.9186	.9180	.9174	.9168	.9162	.9156
23	.9150	.9144	.9138	.9132	.9126	.9121	.9115	.9109	.9103	.9097
24	.9091	.9085	.9079	.9073	.9067	.9061	.9056	.9050	.9044	.9038
25	.9032	.9026	.9021	.9015	.9009	.9003	.8997	.8992	.8986	.8980
26	.8974	.8969	.8963	.8957	.8951	.8946	.8950	.8934	.8929	.8923
27	.8917	.8912	.8906	.8900	.8895	.8889	.8883	.8878	.8872	.8866
28	.8861	.8855	.8850	.8844	.8838	.8833	.8827	.8822	.8816	.8811
29	.8805	.8799	.8794	.8788	.8783	.8777	.8772	.8766	.8761	.8755
30	.8750	.8745	.8739	.8734	.8728	.8723	.8717	.8712	.8706	.8701
31	.8696	.8690	.8685	.8679	.8674	.8669	.8663	.8658	.8653	.8647
32	.8642	.8637	.8631	.8626	.8621	.8615	.8610	.8605	.8600	.8594
33	.8589	.8584	.8578	.8573	.8568	.8563	.8557	.8552	.8547	.8542
34	.8537	.8531	.8526	.8521	.8516	.8511	.8505	.8500	.8495	.8490
35	.8485	.8480	.8475	.8469	.8464	.8459	.8454	.8449	.8444	.8439
36	.8434	.8429	.8424	.8419	.8413	.8408	.8403	.8398	.8393	.8388
37	.8383	.8378	.8373	.8368	.8363	.8358	.8353	.8348	.8343	.8338
38	.8333	.8328	.8323	.8318	.8314	.8309	.8304	.8299	.8294	.8289
39	.8284	.8279	.8274	.8269	.8264	.8260	.8255	.8250	.8245	.8240

TABLE XXIX.—*Continued*

Specific Gravities at $\frac{60°}{60°}$ F. $\left[\frac{15°.56}{15.°56}\text{C.}\right]$ Corresponding to Degrees Baumé for Liquids Lighter than Water

Degrees Baumé.	Tenths of Degrees Baumé.									
	0	1	2	3	4	5	6	7	8	9
40	0.8235	0.8230	0.8226	0.8221	0.8216	0.8211	0.8206	0.8202	0.8197	0.8192
41	.8187	.8182	.8178	.8173	.8168	.8163	.8159	.8154	.8149	.8144
42	.8140	.8135	.8130	.8121	.8121	.8116	.8111	.8107	.8102	.8097
43	.8092	.8088	.8083	.8078	.8074	.8069	.8065	.8060	.8055	.8051
44	.8046	.8041	.8037	.8032	.8028	.8023	.8018	.8014	.8009	.8005
45	.8000	.7995	.7991	.7986	.7982	.7977	.7973	.7968	.7964	.7959
46	.7955	.7950	.7946	.7941	.7937	.7932	.7928	.7923	.7919	.7914
47	.7910	.7905	.7901	.7896	.7892	.7887	.7883	.7878	.7874	.7870
48	.7865	.7861	.7856	.7852	.7848	.7843	.7839	.7834	.7830	.7826
49	.7821	.7817	.7812	.7808	.7804	.7799	.7795	.7791	.7786	.7782
50	.7778	.7773	.7769	.7765	.7761	.7756	.7752	.7748	.7743	.7739
51	.7735	.7731	.7726	.7722	.7718	.7713	.7709	.7705	.7701	.7697
52	.7692	.7688	.7684	.7680	.7675	.7671	.7667	.7663	.7659	.7654
53	.7650	.7646	.7642	.7638	.7634	.7629	.7625	.7621	.7617	.7613
54	.7609	.7605	.7600	.7596	.7592	.7588	.7584	.7580	.7576	.7572
55	.7568	.7563	.7559	.7555	.7551	.7547	.7543	.7539	.7535	.7531
56	.7527	.7523	.7519	.7515	.7511	.7507	.7503	.7499	.7495	.7491
57	.7487	.7483	.7479	.7475	.7471	.7467	.7463	.7459	.7455	.7451
58	.7447	.7443	.7439	.7435	.7431	.7427	.7423	.7419	.7415	.7411
59	.7407	.7403	.7400	.7396	.7392	.7388	.7384	.7380	.7376	.7372
60	.7368	.7365	.7361	.7357	.7353	.7349	.7345	.7341	.7338	.7334
61	.7330	.7326	.7322	.7318	.7315	.7311	.7307	.7303	.7299	.7295
62	.7292	.7288	.7284	.7280	.7277	.7273	.7269	.7265	.7261	.7258
63	.7254	.7250	.7246	.7243	.7239	.7235	.7231	.7228	.7224	.7220
64	.7216	.7213	.7209	.7205	.7202	.7198	.7194	.7191	.7187	.7183
65	.7179	.7176	.7172	.7168	.7165	.7161	.7157	.7154	.7150	.7147
66	.7143	.7139	.7136	.7132	.7128	.7125	.7121	.7117	.7114	.7110
67	.7107	.7103	.7099	.7096	.7092	.7089	.7085	.7081	.7078	.7074
68	.7071	.7067	.7064	.7060	.7056	.7053	.7049	.7046	.7042	.7039
69	.7035	.7032	.7028	.7025	.7021	.7018	.7014	.7011	.7007	.7004

TABLE XXIX.—*Continued*

Specific Gravities of $\frac{60°}{60°}$ F. $\left[\frac{15°.56}{15.°56}\text{C.}\right]$ Corresponding to Degrees Baumé for Liquids Lighter than Water

Degrees Baumé.	Tenths of Degrees Baumé.									
	0	1	2	3	4	5	6	7	8	9
70	0.7000	0.6997	0.6993	0.6990	0.6986	0.6983	0.6979	0.6976	0.6972	0.6969
71	.6965	.6962	.6958	.6955	.6951	.6948	.6944	.6941	.6938	.6934
72	.6931	.6927	.6924	.6920	.6917	.6914	.6910	.6907	.6903	.6900
73	.6897	.6893	.6890	.6886	.6883	.6880	.6876	.6873	.6869	.6866
74	.6863	.6859	.6856	.6853	.6849	.6846	.6843	.6839	.6836	.6833
75	.6829	.6826	.6823	.6819	.6816	.6813	.6809	.6806	.6803	.6799
76	.6796	.6793	.6790	.6786	.6783	.6780	.6776	.6773	.6770	.6767
77	.6763	.6760	.6757	.6753	.6750	.6747	.6744	.6740	.6737	.6734
78	.6731	.6728	.6724	.6721	.6718	.6715	.6711	.6708	.6705	.6702
79	.6699	.6695	.6692	.6689	.6686	.6683	.6679	.6676	.6673	.6670
80	.6667	.6663	.6660	.6657	.6654	.6651	.6648	.6645	.6641	.6638
81	.6635	.6632	.6629	.6626	.6623	.6619	.6616	.6613	.6610	.6607
82	.6604	.6601	.6598	.6594	.6591	.6588	.6585	.6582	.6579	.6576
83	.6573	.6570	.6567	.6564	.6560	.6557	.6554	.6551	.6548	.6545
84	.6542	.6539	.6536	.6533	.6530	.6527	.6524	.6521	.6518	.6515
85	.6512	.6509	.6506	.6503	.6500	.6497	.6494	.6490	.6487	.6484
86	.6482	.6479	.6476	.6473	.6470	.6467	.6464	.6461	.6458	.6455
87	.6452	.6449	.6446	.6443	.6440	.6437	.6434	.6431	.6428	.6425
88	.6422	.6419	.6416	.6413	.6410	.6407	.6404	.6401	.6399	.6396
89	.6393	.6390	.6387	.6384	.6381	.6378	.6375	.6372	.6369	.6367
90	.6364	.6361	.6358	.6355	.6352	.6349	.6346	.6343	.6341	.6338
91	.6335	.6332	.6329	.6326	.6323	.6321	.6318	.6315	.6312	.6309
92	.6306	.6303	.6301	.6298	.6295	.6292	.6289	.6286	.6284	.6281
93	.6278	.6275	.6272	.6270	.6267	.6264	.6261	.6258	.6256	.6253
94	.6250	.6247	.6244	.6242	.6239	.6236	.6233	.6231	.6228	.6225
95	.6222	.6219	.6217	.6214	.6211	.6208	.6206	.6203	.6200	.6197
96	.6195	.6192	.6189	.6186	.6184	.6181	.6178	.6176	.6173	.6170
97	.6167	.6165	.6162	.6159	.6157	.6154	.6151	.6148	.6146	.6143
98	.6140	.6138	.6135	.6132	.6130	.6127	.6124	.6122	.6119	.6116
99	.6114	.6111	.6108	.6106	.6103	.6100	.6098	.6095	.6092	.6090
100	.6087									

asphalt binder is to be used instead the weight of the membrane may be taken as 15 per cent less than the values given in the table.

The weights and thicknesses noted in columns 3, 4 and 5, are average values of many specimens actually weighed and measured. The rest of the items were calculated. The two thicknesses of binder film, $\frac{1}{16}$ inch and $\frac{3}{32}$-inch were assumed because $\frac{1}{16}$-inch is the thickness of a film of binder when carefully applied with a single mopping, while the $\frac{3}{32}$-inch film is obtained with a double mopping which is sometimes called for on important work. Where the $\frac{3}{32}$-inch thickness of film is used only half the number of plies required for the $\frac{1}{16}$ inch would be necessary under the same conditions of water pressure, etc.

While jute burlap weighing 7, 8, 9, 10 and even 11 ounces is sometimes used, the $7\frac{1}{2}$-ounce open-mesh variety is most extensively used. No. 26 felt is a very commonly used grade, though anywhere from No. 20 to No. 50 felts are used for membrane waterproofing. The heavier-weight felts are usually used for roofing. The medium-weight cotton fabrics are most extensively used for membrane waterproofing. These weights range from 4 to 6 ounces per square yard.

For obtaining weights of complete membranes consisting of more than 6 plies, the simplest way is to draw a curve on cross-section paper for three or four values in which the number of plies are the abscissæ and the weights are the ordinates. It will be found that the curves so drawn are straight lines and may be produced to give the values sought.

Table XXXII, " Thickness of Waterproofing Materials for Different Water Pressures," shows the approximate number of felt and fabric plies, thicknesses of mortar and mastic layers and the number of courses of various kinds of waterproofing materials (applicable to the membrane or surface-coating types of waterproofing), required under various heads of water. It is compiled from a careful study of the general field practice in waterproofing underground structures. The bituminous sheet mastic layers, the brick-in-mastic courses and the different membranes, should be protected, or rather, encased in masonry, both to support them and protect them from climatic temperature changes. The surface-mortar coats, $\frac{1}{2}$ inch thick or less, must not be put on in several layers to make up there quired thickness, but the thicker mortar coats may have a scratch coat, and together with the " finish coat " should make up the required thickness. Both the thin and thick mortar coats must be applied continuously over or on the structure until completed.

Table XXXIII, " Volumes and Weights of Ingredients used in

Brick-in- (Asphalt) Mastic Waterproofing," is based on present-day practice of laying common bricks in a bituminous mastic to form a thick waterproofing envelope about an underground structure. It is further based on the use of asphalt only for making the mastic, but coal-tar pitch can be used with practically equally good results. The weight of asphalt was assumed to be 66 pounds per cubic foot. The average weight of coal-tar pitch is 76 pounds per cubic foot.

The size of joints between bricks in the brick-in-mastic envelope is of vital importance. Bricks laid close together, that is, without joints, vitiate the function of the waterproofing envelope. It is obvious that the bricks do not constitute a waterproofing medium

TABLE XXX.—SPECIFIC GRAVITY AND COEFFICIENT OF EXPANSION OF VARIOUS MATERIALS

Substance.	Specific Gravity at 62° F. (Aver.).	Volumetric Coefficient of Expansion Per Deg. F. (Aver.).	Substance.	Specific Gravity at 62° F. (Aver.).	Lineal Coefficient of Expansion Per Deg. F. (Aver.).
Alcohol (100%)	0.79	.00058	Asbestos	2.81	
Asphalt, artificial (Eastern petroleum), residuum at 21° Baumé	1.3	.000507	Brick (common)	1.922	.00000306
Asphalt, Bermudez Lake.	1.06[1]	.00035[2]	Brick masonry	2.00	.0000031
Asphalt, Mexican	1.036[1]	.000288[4]	Cedar	0.45	
Asphalt, Trinidad Lake (crude)	1.21	.00035[2]	Clay (Dry lumps)	1.80	
Asphalt, Trinidad, liquid	0.96	.00030[3]	Concrete (stone)	2.33	.0000068
Beeswax	0.955	.000150	Copper	8.88	.0000093
Castor oil	0.96	.....	Glass	3.1	.0000041
China wood oil	0.944	.000355	Granite (New Hamp.)	2.66	.0000047
Caoutchouc (rubber)	0.94	.....	Graphite	2.26	.0000044
Creosote oil	1.07	.....	Gypsum	2.27	
Fats	0.935	.....	Hydrated lime	2.12	
Gutta Percha	0.99	.000332	Iron (wrought)	7.70	.0000067
Ice	0.92	.0000408[8]	Lead	11.40	.0000159
Linseed oil	0.927	.000380[7]	Lime (slaked)	1.35	
Paraffin (hard)	0.908	.000568	Limestone	2.72	.0000045
Oils (vegetable)	0.925	.....	Marble	2.65	.0000056
Oils (mineral)	0.915	.....	Mortar (1 : 2)	1.84	.00000561
Petroleum, Mexican asphaltic (crude)	0.878	.000392	Oak (white)	0.77	.0000027
Pitch, coal tar	1.298	.000243[5]	Pine (long leaf)	0.61	.0000030
Pitch, oil tar	1.218	.000258[6]	Plaster (white)	.....	.0000092
Rosin	1.1	.....	Portland cement (set)	2.95	.0000067
Rubber (sheet)	1.5	.....	Rubble masonry	2.48	.0000035
Tallow	0.94	.....	Sandstone	2.44	.0000061
Turpentine	0.860	.000454[7]	Slate	2.81	.0000058
Water (4° C.)	1.000	.000086	Steel	7.80	.0000061
Wax	0.965	.....	Terra Cotta	1.9	
			Tiles	2.20	
			Tin (rolled)	7.40	.0000117
			Zinc (rolled)	7.05	.000017

[1] Specific gravity at 77 deg. Fahr.

[2] Asphalt having penetration between 0.50 and 0.75 cm. at 77 deg. Fahr. (100 grams, 5 seconds). Coefficient between 77 and 300 deg. Fahr.

[3] Asphalt is for cold application. Coefficient between 77 and 100 deg. Fahr.

[4] Asphalt having penetration between 0.65 and 0.83 cm. at 77 deg. Fahr.

[5] Straight-run product having a melting-point of 137 deg. Fahr. by the cube-in-water method. Coefficient between 60 and 180 deg. Fahr.

[6] Melting point 160 deg. Fahr. by the cube-in-water method. Coefficient between 60 and 180 deg. Fahr.

[7] Between 50 deg. and 100 deg. Fahr.

[8] At + 30 deg. Fahr., reducing to .0000197 at − 30 deg. Fahr.

TABLE XXXI.—WEIGHT AND THICKNFSS OF BURLAP, FELT AND COTTON FABRIC MEMBRANES WITH COAL-TAR PITCH BINDER*

Number of Plies.	Binder Films.		7½ Oz. (Open Mesh) Jute Burlap.			Medium Weight Felt (No. 26).			Medium Weight Cotton Fabrics. (66×68 Threads Per Sq. In.)		
	No.	Thickness (In.).	Weight of Membrane (Lb.). Per Sq. Yd.	Thickness (In.).	Total Binder in Membrane (Lb.). Per Sq. Yd.	Weight of Membrane (Lb.). Per Sq. Yd.	Thickness (In.).	Total Binder in Membrane (Lb.). Per Sq. Yd.	Weight of Membrane (Lb.). Per Sq. Yd.	Thickness (In.).	Total Binder in Membrane (Lb.). Per Sq. Yd.
1-ply untreated	..	..	.42*a*	1/32	.....	.51	1/32	.....	.29	1/64	.....
1-ply saturated	..	..	.95*b*	1/32	.....	1.08*b*	1/32	.....	.88*b*	1/32	.....
1-ply saturated and coated	..	..	1.35*c*	3/64	.....	.....	..	.....	.....	..	.....
1-ply membrane (applied)	2	1/16 *d*	8.46	11/64	7.11*e*	8.17	5/32	7.09	7.97	5/32	7.09
1-ply membrane (applied)	2	3/32 *d*	12.06	15/64	10.71	11.77	7/32	10.69	11.57	7/32	10.69
2-ply membrane (applied)	3	1/16	13.39	9/32	10.68	11.71	1/4	10.63	12.39	1/4	10.63
2-ply membrane (applied)	3	3/32	18.79	8/8	16.08	17.11	11/32	16.03	17.79	11/32	16.03
3-ply membrane (applied)	4	1/16	18.31	25/64	14.25	13.88	11/32	14.18	16.82	11/32	14.18
3-ply membrane (applied)	4	3/32	25.51	33/64	21.42	24.56	15/32	21.38	24.02	15/32	21.38
4-ply membrane (applied)	5	1/16	23.23	1/2	17.82	22.04	7/16	17.72	21.24	7/16	17.72
4-ply membrane (applied)	5	3/32	32.23	21/32	26.82	31.04	19/32	26.72	30.24	19/32	26.72
5-ply membrane (applied)	6	1/16	28.16	39/64	21.39	26.67	17/32	21.26	25.67	17/32	21.26
5-ply membrane (applied)	6	3/32	38.32	51/64	32.19	34.97	23/32	32.06	36.47	23/32	32.06
6-ply membrane (applied)	7	1/16	33.08	23/32	24.96	31.29	5/8	24.81	30.09	5/8	24.81
6-ply membrane (applied)	7	3/32	45.68	15/16	37.56	43.89	27/32	37.38	42.69	27/32	37.38

* Weight of pitch binder taken as 76 lb. per cu. ft., or, about .044 lb. per cu. in. Weight of refined asphalt taken as 66 lb. per cu. ft., or, about .038 lb. per cu. in.

a. The standard weight for jute burlap is that of a strip 40 inches wide, 1 yd. long, weighing 7½ oz.; hence 1 sq. yd. weighs 6.75 oz. (.42 lb).

b. 0.95, 1.08, and 0.88 lb. include the weights of saturants which are, respectively, 0.53, 0.59, and 0.59 lb.

c. 1.35 lb. includes the weights of saturant (.53 lb.) and coating (.40 lb).

d. Weight of 1 sq. yd. of binder film, 1/16 in. thick = 3.54 lb.; 3/32 in. thick, = 5.34 lb.

e. Weight of binder used with jute fabric includes the weight of pitch filling the open meshes of the fabric. The volume of the open meshes in 1 sq. yd. of untreated jute burlap is 10.5 cu. in.; in the treated burlap, it is 4 cu. in., or about 40 per cent of the voids of the untreated jute burlap.

in themselves, they merely furnish "body," depth and weight to the envelope and economy in the waterproofing system. The bituminous mastic alone is the waterproofing medium, hence the more of it present—within economical limits, of course—the better. The smallest joint should be not less than $\frac{1}{8}$ inch and the largest need not be more than $\frac{1}{4}$ inch. Therefore the volume and weight of the various ingredients have been calculated on this basis; also on the empirical basis of a 20 per cent and 30 per cent reduction in volume of mastic, as compared to volume of ingredients (see Chapter VII), mixed in proportions of 2 : 1 : 1 and 1 : 1 : 1, respectively.

TABLE XXXII.—THICKNESS OF WATERPROOFING MATERIALS REQUIRED FOR DIFFERENT WATER PRESSURES

Head of water (Ft.).	Number of Plies, Layers or Courses.												
	Coal-tar Pitch and Felt.	Coal-tar Pitch and Jute (*a*) Fabric.	Coal-tar Pitch and Cotton (*b*) Fabric.	Coal-tar Pitch,* Felt and Fabric.	Asphalt and Felt.	Asphalt and Jute (*a*) Fabric.	Asphalt and Cotton (*b*) Fabric.	Asphalt,* Felt and Fabric.	Coal-tar Pitch (or Asphalt) and Burlap.	Asphlat or Pitch Mastic† (Thickness of Layer, Ins.).	Brick and Asphalt or Pitch Mastic‡ (No. of Courses).	Portland Cement Mortar on Outside of Substructure.	
												1 : 1 Proportion (Thickness, Ins.).	1 : 2 Proportion (Thickness, Ins.).
0	2	..	..	..	2	..	..	..	..	$\frac{3}{8}$	..	$\frac{1}{4}$	$\frac{3}{8}$
3	2	2	2	..	2	2	2	..	2	$\frac{3}{8}$	..	$\frac{1}{4}$	$\frac{3}{8}$
6	3	2	2	2	3	2	2	2	3	$\frac{1}{2}$	..	$\frac{3}{8}$	$\frac{1}{2}$
9	4	3	3	3	4	3	3	3	3	$\frac{1}{2}$	1*c*	$\frac{3}{8}$	$\frac{1}{2}$
12	5	3	3	5	5	3	3	5	4	$\frac{3}{4}$	1*c*	$\frac{1}{2}$	$\frac{5}{8}$
15	6	4	4	5	6	4	4	5	4	$\frac{3}{4}$	1*c*	$\frac{5}{8}$	$\frac{3}{4}$
18	7	4	4	5	7	4	4	5	5	1	1*d*	$\frac{5}{8}$	$\frac{3}{4}$
21	7	5	5	7	7	5	5	7	5	1	1*d*	$\frac{3}{4}$	1
24	8	6	6	7	8	6	6	7	6	$1\frac{1}{4}$	1*d*	$\frac{3}{4}$	1
27	8	7	7	7	8	7	7	7	6	$1\frac{1}{4}$	2*c*	1	$1\frac{1}{4}$
30	9	7	7	8	9	7	7	8	7	$1\frac{1}{4}$	2*c*	1	$1\frac{1}{4}$
33	9	8	8	8	9	8	8	8	7	$1\frac{1}{2}$	2*c*	$1\frac{1}{4}$	$1\frac{1}{2}$
36	10	8	8	9	10	8	8	9	8	$1\frac{1}{2}$	2*d*	$1\frac{1}{4}$	$1\frac{1}{2}$
39	10	9	9	9	10	9	9	9	8	$1\frac{1}{2}$	2*d*	$1\frac{1}{2}$	$1\frac{3}{4}$
42	10	9	9	9	10	9	9	9	9	$1\frac{3}{4}$	2*d*	$1\frac{1}{2}$	2

* Each third ply to be either jute or cotton fabric.

† Sheet mastic composed of 15 to 25 per cent of bitumen; sand, grit and cement or limestone dust in equal proportions.

‡ Mastic (for brick and mastic) composed of 35 to 45 per cent of bitumen, and equal parts of sand and cement, or limestone dust.

(*a*) Open-mesh variety.

(*b*) Closed-mesh variety.

(*c*) Bricks laid on $8 \times 3\frac{1}{2}$ inch face, on horizontal and against vertical surfaces.

(*d*) Bricks laid on $8 \times 2\frac{1}{4}$ inch face, on horizontal surfaces, but on the $3\frac{1}{2}$-inch face against vertical surfaces.

TABLE XXXIII.—VOLUMES AND WEIGHTS OF INGREDIENTS USED IN BRICK-IN-(ASPHALT) MASTIC WATERPROOFING

Ingredients.	Proportions of Mastic by Volume (Asphalt : Sand : Mineral Dust).	Bearing Face of Brick.	Width of Joint. (In.).	Volume of Ingredients (Cubic Feet).			Weight of Ingredients (Pounds).			Number of Bricks.	
				Per Sq. Yd.		Per Cu. Yd. of Finished Material	Per Sq. Yd.		Per Cu. Yd. of Finished Material.	Per Sq. Yd., 1 Course.	Per Cu. Yd.
				1 Course of Brick.	2 Courses of Brick.		1 Course of Brick.	2 Courses of Brick.			
BRICK-IN-MASTIC:											
Mastic in brick-in-mastic ...	1 : 1 : 1	8×3½	⅛	0.27	0.45	2.7	29.5	48.7	291	..	...
	1 : 1 : 1	8×3½	¼	0.54	0.88	5.0	58.2	96.0	544	..	...
	1 : 1 : 1	8×2¼	⅛	0.36	0.64	2.7	39.6	69.1	291	..	...
	1 : 1 : 1	8×2¼	¼	0.71	1.23	5.0	77.2	134.0	544	..	...
	2 : 1 : 1	8×3½	⅛	0.27	0.45	2.7	25.8	42.6	255	..	...
	2 : 1 : 1	8×3½	¼	0.54	0.88	5.0	50.9	84.0	476	..	...
	2 : 1 : 1	8×2¼	⅛	0.36	0.64	2.7	34.6	60.4	255	..	...
	2 : 1 : 1	8×2¼	¼	0.71	1.23	5.0	67.5	117.1	476	..	...
Bitumen in brick-in-mastic..	1 : 1 : 1	8×3½	⅛	0.12	0.19	1.2	7.7	12.8	77	..	...
	1 : 1 : 1	8×3½	¼	0.23	0.38	2.2	15.3	25.3	143	..	...
	1 : 1 : 1	8×2¼	⅛	0.16	0.28	1.2	10.4	18.2	177	..	...
	1 : 1 : 1	8×2¼	¼	0.30	0.53	2.2	20.3	35.2	143	..	...
	2 : 1 : 1	8×3½	⅛	0.16	0.27	1.6	10.7	17.7	106	..	...
	2 : 1 : 1	8×3½	¼	0.32	0.53	3.0	21.2	35.0	198	..	...
	2 : 1 : 1	8×2¼	⅛	0.22	0.38	1.6	14.4	25.1	106	..	...
	2 : 1 : 1	8×2¼	¼	0.43	0.74	3.0	28.1	48.8	198	..	...
Sand in brick-in-mastic.....	1 : 1 : 1	8×3½	⅛	0.12	0.19	1.2	10.0	16.5	99	..	...
	1 : 1 : 1	8×3½	¼	0.23	0.38	2.2	19.7	32.5	184	..	...
	1 : 1 : 1	8×2¼	⅛	0.16	0.28	1.2	13.4	23.4	99	..	...
	1 : 1 : 1	8×2¼	¼	0.32	0.53	2.2	26.1	45.4	184	..	...
	2 : 1 : 1	8×3½	⅛	0.08	0.13	0.8	6.9	11.4	68	..	...
	2 : 1 : 1	8×3½	¼	0.16	0.26	1.5	13.7	22.5	128	..	...
	2 : 1 : 1	8×2¼	⅛	0.11	0.19	0.8	9.3	16.2	68	..	...
	2 : 1 : 1	8×2¼	¼	0.21	0.37	1.5	18.1	31.4	128	..	...

Mineral dust in brick-in-mastic	1 : 1 : 1	8×3½	⅛	0.12	0.19	1.2	11.7	19.4	116	..	...
	1 : 1 : 1	8×3½	¼	0.23	0.38	2.2	23.2	38.3	217	..	...
	1 : 1 : 1	8×2¼	⅛	0.16	0.28	1.2	15.8	27.5	116	..	...
	1 : 1 : 1	8×2¼	¼	0.30	0.53	2.2	30.8	53.4	217	..	...
	2 : 1 : 1	8×3½	⅛	0.08	0.13	0.8	8.1	13.4	80	..	...
	2 : 1 : 1	8×3½	¼	0.16	0.26	1.5	16.1	26.5	150	..	...
	2 : 1 : 1	8×2¼	⅛	0.11	0.19	0.8	10.9	19.1	80	..	...
Finished brick-in-mastic	2 : 1 : 1	8×2¼	¼	0.21	0.37	1.5	21.3	37.0	150	..	...
	1 : 1 : 1	8×3½	⅛	1.9	3.6	...	230	450	3331	44	667
	1 : 1 : 1	8×3½	¼	2.1	3.9	...	249	478	3294	42	603
	1 : 1 : 1	8×2¼	⅛	2.8	5.5	...	346	681	3331	67	667
	1 : 1 : 1	8×2¼	¼	3.0	5.8	...	364	707	3294	63	603
	2 : 1 : 1	8×3½	⅛	1.9	3.6	...	226	444	3295	44	667
	2 : 1 : 1	8×3½	¼	2.1	3.9	...	242	466	3225	42	603
	2 : 1 : 1	8×2¼	⅛	2.8	5.5	...	341	672	3295	67	667
	2 : 1 : 1	8×2¼	¼	3.0	5.8	...	354	690	3225	63	603
MASTIC:											
Bitumen in mastic	1 : 1 : 1	.....	..	....	....	11.7	....	....	772	..	...
	2 : 1 : 1	.....	..	....	....	16.2	....	....	1069	..	...
Sand in mastic	1 : 1 : 1	.....	..	....	....	11.7	....	....	994	..	...
	2 : 1 : 1	....	..	....	....	8.1	....	....	688	..	...
Mineral dust in mastic	1 : 1 : 1	.....	..	....	....	11.7	....	....	1170	..	...
	2 : 1 : 1	.....	..	....	....	8.1	....	....	810	..	...
	1 : 1 : 1	.....	..	....	....	....	....	....	2937	..	...
Finished mastic*	2 : 1 : 1	.....	..	....	....	....	....	....	2568	..	...
BRICK†											
Laid close together	.....	8×3½	0	1.69	3.38	2.7	211	422	3375	46	741
	.....	8×2¼	0	2.61	5.22	2.7	328	656	3375	72	741

NOTE.—Weight of brick per cu. in. =.072 lb.; weight of 1 brick =4.56 lbs.

* Weight of mastic, 1 : 1 : 1 proportion, =.063 lb. per cu. in.; 2 : 1 : 1 =.055 lb. per cu. in.

† Average size of brick used for brick-in-mastic, 8×3½×2¼ in; volume of one brick =63 cu. in.

Table XXXIV, "Pressure Exerted by Water Beneath Floors and Against Walls," is based on the principles of hydrostatic pressure, which are, (1) the pressure on the base of a vessel containing water is equal to the height of water above the base, times its area; (2) the average water pressure on the side of a vessel is equal to one-half the height of the water in the vessel, times the area of the vertical surface in contact with the water; (3) the pressure of water is transmitted equally in all directions. The type of waterproofing is often governed by the water pressure it will have to resist as judged by the height of ground or mean high water level above the base of the structure to be waterproofed. The table converts this height into pounds pressure for each of the above three conditions.

TABLE XXXIV.—PRESSURE EXERTED BY WATER BENEATH FLOORS AND AGAINST WALLS

Hydrostatic Head—Feet.	Pressure per Square Inch—Lbs.	Lifting Pressure per Square Foot (Under Floor)—Lbs.	Average Pressure per Square Foot on Wall Surface Affected.—Lbs.
0.5	0.21	31.2	15.6
1.0	0.43	62.5	31.2
2.0	0.86	125.0	62.5
3.0	1.30	187.5	93.7
4.0	1.73	250.0	125.0
5.0	2.17	312.5	156.2
6.0	2.60	375.0	187.5
8.0	3.47	500.0	250.0
10.0	4.34	625.0	312.5
12.0	5.21	750.0	375.0
15.0	6.51	937.5	468.7
20.0	8.68	1250.0	625.0
25.0	10.85	1562.5	781.2
30.0	13.02	1875.0	937.5
40.0	17.36	2500.0	1250.0
60.0	26.04	3750.0	1875.0
80.0	34.72	5000.0	2500.0
100.0	43.40	6250.0	3125.0

Table XXXV, "Approximate Weight and Thickness of Various Sheet Metals for Roofings, Gutters and Flashings," gives the weight, thickness and gauge number of various sheet metals commonly used for gutters, flashings, and roofings. Sheet metal is usually designated by the weight of a superficial foot, in pounds or ounces, or by some standard gauge. All tin, iron and steel are figured on the U. S. Standard gauge; copper is figured on the Brown & Sharpe gauge;

TABLE XXXV.—APPROXIMATE WEIGHT AND THICKNESS OF VARIOUS SHEET METALS FOR ROOFS, GUTTERS AND FLASHINGS

Approximate Thickness. (Inches).		Tin, Iron, Steel.		Galvanized Sheets.		Corrugated Galvanized Sheets, Lb. Per Sq. Ft. (Corrugations in Inches).							Copper.		Lead.	Zinc.	
Fraction.	Decimal.	U. S. Standard Gauge.	Lb. Per Sq. Ft.	Gal'd Gauge.	Lb. Per Sq. Ft.	U. S. Standard Gauge.	⅝	1¼	2	2½	3	5	B. & S. Gauge	Lb. Per Sq. Ft.	(No Gauge) Lb. Per Sq. Ft.	Zinc Gauge.	Lb. Per Sq. Ft.
5/32	.156	9	6.25	..	....	9	....	....	....	....	....	....	..	....	9.00	..	....
...	.144	..	....	..	....	..	....	....	....	....	....	....	7	6.54	....	..	....
9/64	.141	10	5.62	10	5.78	10	....	....	....	....	....	....	....	....	8.00	..	....
...	.128	..	....	..	....	..	....	....	....	....	....	....	8	5.82	....	..	....
1/8	.125	11	5.00	11	5.16	11	....	....	....	....	....	....	..	....	7.29	..	....
...	.120	..	....	..	....	..	....	....	....	....	....	....	..	....	7.00	..	....
...	.114	..	....	..	....	..	....	....	....	....	....	....	9	5.18	....	..	....
7/64	.109	12	4.38	12	4.53	12	....	....	....	4.88	....	....	..	....	6.38	..	....
...	.102	..	....	..	....	..	....	....	....	....	....	....	10	4.62	6.00	..	....
3/32	.094	13	3.75	13	3.91	13	....	....	....	....	....	....	..	....	5.47	..	....
...	.091	..	....	..	....	..	....	....	....	....	....	....	11	4.11	....	22	3.37
...	.086	..	....	..	....	..	....	....	....	....	....	....	..	....	5.00	..	....
...	.081	..	....	..	....	..	....	....	....	....	....	....	12	3.66	....	..	....
5/64	.078	14	3.12	14	3.28	14	....	....	....	3.54	....	3.54	..	....	4.56	21	3.00
9/128	.070	15	2.81	15	2.97	15	....	....	....	....	....	....	13	3.26	4.00	20	2.62
1/16	.062	16	2.50	16	2.66	16	....	....	2.86	2.86	2.86	2.86	14	2.90	3.64	19	2.25
9/160	.056	17	2.25	17	2.41	17	....	....	....	....	....	....	15	2.58	....	18	2.06
1/20	.050	18	2.00	18	2.16	18	....	....	2.32	2.32	2.32	2.32	16	2.30	3.00	17	1.87
7/160	.045	..	....	..	....	..	....	....	....	....	....	....	17	2.05	2.73	16	1.68

TABLE XXXV.—APPROXIMATE WEIGHT AND THICKNESS OF VARIOUS SHEET METALS FOR ROOFS, GUTTERS AND FLASHINGS—(*Continued*)

Approximate Thickness. (Inches).		Tin, Iron, Steel.		Galvanized Sheets.		Corrugated Galvanized Sheets, Lb. Per Sq. Ft. (Corrugations in Inches).							Copper.		Lead.	Zinc.	
Fraction.	Decimal.	U. S. Standard Gauge.	Lb. Per Sq. Ft.	Gal'd Gauge.	Lb. Per Sq. Ft.	U. S. Standard Gauge.	⅛	1¼	2	2½	3	5	B. & S. Gauge.	Lb. Per Sq.Ft.	(No. Gauge) Lb. Per Sq.Ft.	Zinc Gauge.	Lb. Per Sq. Ft.
...	.044	19	1.75	19	1.91	19	....	....	....	....	....	....	..	....	....	..	....
3/80	.038	20	1.50	20	1.66	20	....	1.85	1.78	1.78	1.78	1.78	18	1.82	....	15	1.50
11/320	.036	..	....	..	....	..	....	....	....	....	....	....	19	1.63	....	14	1.35
...	.034	21	1.38	21	1.53	21	....	....	1.65	1.65	1.65	1.65	..	....	2.00	..	....
1/32	.031	22	1.25	22	1.41	22	....	1.57	1.51	1.51	1.51	1.51	20	1.45	1.82	13	1.20
9/320	.028	23	1.12	23	1.28	23	....	....	1.38	1.38	1.38	1.38	21	1.29	....	12	1.05
1/40	.025	24	1.00	24	1.16	24	1.29	1.29	1.24	1.24	1.24	1.24	22	1.15	....	11	0.90
7/320	.022	25	0.88	25	1.03	25	....	....	1.11	1.11	1.11	1.11	23	1.02	....	..	....
...	.020	..	....	..	....	..	....	....	....	....	....	....	24	0.91	....	10	0.75
3/160	.019	26	0.75	26	0.91	26	1.01	1.01	0.98	0.98	0.98	0.98	25	0.81	....	9	0.67
11/640	.017	27	0.69	27	0.84	27	0.94	0.94	0.91	0.91	0.91	0.91	..	....	1.00	..	....
1/64	.016	28	0.62	28	0.78	28	0.87	0.87	0.85	0.85	0.85	0.85	26	0.72	0.91	8	0.60
9/640	.014	29	0.56	29	0.72	29	....	....	....	....	....	....	27	0.64	....	7	0.52
...	.013	..	....	..	....	..	....	....	....	....	....	....	28	0.57	....	..	....
1/80	.0125	30	0.50	30	0.66	30	....	....	....	....	....	....	..	....	....	6	0.45

zinc has a gauge of its own, while lead is usually figured at so many pounds to the square foot, such as 2-pound lead, 3-pound lead, etc. Galvanized sheets have a gauge based on their weights, and not on the thickness. Corrugated galvanized sheets usually figured on the U. S. Standard gauge, are made in standard widths of corrugations, and in standard lengths, ranging from 5 to 10 feet, with a maximum length of 12 feet.

Table XXXVI, "Weights of Roof Coverings," gives closely approximate weights of various roof coverings and sheathings. These figures are very useful for designing and estimating.

TABLE XXXVI.—WEIGHTS OF ROOF COVERINGS

Material.	Average Weight in Lbs. per Sq. Ft of Roof.
Ash wood sheathing, 1-in. thick	5.0
Asbestos shingles (laid French method)	2.8
Asbestos shingles (laid American method)	4.0
Chestnut wood sheathing, 1-in. thick	4.0
Copper, 16 oz., standing seam	1.3
Clay tiles (plain) $10\frac{1}{2}$ by $6\frac{1}{4}$ by $\frac{5}{8}$ ins., $5\frac{1}{4}$ in. to the weather	18.0
Clay tiles (Spanish) $14\frac{1}{2}$ by $10\frac{1}{2}$ ins., $7\frac{1}{4}$ ins. to the weather	8.5
Felt and asphalt (3 plies) (without sheathing)	2.0
Felt, asphalt and gravel (6 plies) (without sheathing)	8.0–10.0
Glass, $\frac{1}{8}$-in. thick	1.8
Hemlock sheathing, 1-in. thick	2.0
Iron, corrugated, No. 16, B.W.G. (without sheathing)	3.6
Iron, galvanized, flat No. 16, B.W.G. (without sheathing)	3.0
Maple sheathing, 1-in. thick	4.0
Oak sheathing, 1-in. thick	5.0
Sheet iron, $\frac{1}{16}$-in. thick	3.0
Sheet-lead, about $\frac{1}{8}$-in. thick	8.0
Slag roofing (four-ply)	4.0
Slate, $\frac{1}{4}$-in. thick	9.0
Slate, $\frac{3}{16}$-in. thick (double-lap)	6.8
Slate, $\frac{1}{8}$-in. thick (3 in. double-lap)	4.5
Spruce sheathing, 1-in. thick	2.5
Terne plate (tin), IC (without sheathing)	0.5
Terne plate (tin), IX (without sheathing)	0.7
Tiles, 2 in. to 4 in. thick (plain, with mortar)	15.0
White pine sheathing, 1-in. thick	2.5
Wood shingles, 6 by 18 ins., $\frac{1}{3}$ to the weather	2.0
Yellow pine sheathing, 1-in. thick	4.0
Zinc No. 20, B.W.G	1.5

Table XXXVII, "Square Feet Covered by 1000 Wooden Shingles," gives the covering capacity of a thousand wooden shingles of various lengths and widths, according to fractions exposed to the weather. The number of shingles per 100 square feet of roof surface can be easily calculated therefrom. In doing so about 5 per cent should be added for hip roofs and about 10 per cent for irregular roofs with dormer windows. The number of nails required is usually about three times the number of shingles.

Table XXXVIII, "Number of Slates and Pounds of Nails for Roofing," gives the number of slate shingles and quantity of nails required to cover 100 square feet of roof surface. These values are also applicable to flat, baked-clay tiles.

Table XXXIX, "Size, Length, Gauge and Weight of Roofing Nails," will prove helpful to the roofer. Nails shorter than ½ inch are generally not used. Nails with large flat heads and barbed shanks are best for all roofing purposes.

TABLE XXXVII.—SQUARE FEET COVERED BY ONE THOUSAND WOODEN SHINGLES

Exposed to Weather, In.	Length in Inches.									
	16			18			20	24		
	Width in Inches.			Width in Inches.			Width Inches.	Width in Inches.		
	4	5	6	4	5	6	6	5	6	7
3	77	98	119							
3½	90	114	139							
4	103	130	159							
4½	116	146	179							
5	129	162	199	129	162	199				
5½	142	178	219	142	178	219				
6	155	194	239	155	194	239	239			
6½	....	....	....	168	210	259	259			
7	....	....	....	181	226	279	279	226	279	329
7½	....	....	....	194	242	299	299	242	299	353
8	....	....	....	207	258	319	319	258	319	377
8½	....	....	....	....	....	....	339	274	339	401
9	....	....	....	....	....	....	359	290	359	425
9½	....	....	....	....	....	....	....	306	379	449
10	....	....	....	....	....	....	....	322	399	473
10½	....	....	....	....	....	....	....	338	419	479
11	....	....	....	....	....	....	....	354	439	521
11½	....	....	....	....	....	....	....	370	459	545
12	....	....	....	....	....	....	....	386	479	569

TABLE XXXVIII.—NUMBER OF SLATES AND POUNDS OF NAILS REQUIRED FOR ROOFING *

(PER 100 SQ. FT.)

Size of Slates (Inches).	No. of Inches Exposed When Laid.	No. per Square (100 Sq. Ft.).	Weight of Galvanized Nails per Square.		
			Lb.	Oz.	*d.*
14×24	10½	98	1	6	4
12×24	10½	115	1	10	4
12×22	9½	126	1	12	4
11×22	9½	138	1	15	4
12×20	8½	142	2	0	4
10×20	8½	170	2	6	4
12×18	7½	160	1	13	3
10×18	7½	192	2	3	3
9×18	7½	214	2	7	3
12×16	6½	185	2	2	3
10×16	6½	222	2	8	3
9×16	6½	247	3	0	3
8×16	6½	277	3	2	3
10×14	5½	262	3	0	3
8×14	5½	328	3	12	3
7×14	5½	374	4	4	3
8×12	4½	400	4	9	3
7×12	4½	458	5	3	3
6×12	4½	533	6	1	3

* American Civil Engineers' Pocket Book, p. 404 (2d Edition).

TABLE XXXIX.—SIZE, LENGTH, GAUGE AND WEIGHT OF ROOFING NAILS*

Slating Nails.				Shingle Nails.				Felt Roofing Nails, Large Head, Barbed.				Roofing Nails, Barbed.			
Size.	Length, In.	Gauge No.	Approx. No. Per Lb.	Size.	Length, In.	Gauge No.	Approx. No. Per Lb.	Length, In.	Head, In.	Gauge No.	Head, In.	Gauge No.	Length, In.	Gauge No.	Approx. No. Per Lb.
2*d*	1	12	411	3*d*	1¼	13	429	¾	½	8	7/16	10	¾	13	714
3*d*	1¼	10½	225	4*d*	1½	12	274	⅞	½	8	7/16	10	⅞	12	469
4*d*	1½	10½	187	5*d*	1¾	12	235	1	½	8	7/16	10	1	12	411
5*d*	1¾	10	142	6*d*	2	12	204	1⅛	½	8	7/16	10	1⅛	13	365
6*d*	2	9	103	7*d*	2¼	11	139	1¼	½	8	7/16	10	1¼	11	251
				8*d*	2½	11	125	1½	½	8	7/16	10	1⅜	10	230
				9*d*	2¾	11	114	1¾	½	8	7/16	10	1½	10	176
				10*d*	3	10	83	..	..	..	..	..	1¾	10	151
													2	9	103

* As manufactured by Pittsburgh Steel Co.

APPENDICES

APPENDIX I

EXPLANATION OF MECHANICAL ANALYSIS * FOR GRADING CONCRETE AGGREGATES

MECHANICAL analysis consists in separating the particles or grains of a sample of any material, such as broken stone, gravel, sand or cement, into the various sizes of which it is composed, so that the material may be represented by a curve (see Figs. 139–140), each of whose ordinates is the percentage of the weight of the total sample which passes a sieve having holes of a diameter represented by the distance of this ordinate from the origin in the diagram.

The objects of mechanical analysis curves as applied to concrete aggregates are (1) to show graphically the sizes and relative sizes of the particles; (2) to indicate what sized particles are needed to make the aggregate more nearly perfect and so enable the engineer to improve it by the addition or substitution of another material; and (3) to afford means for determining best proportions of different aggregates.

To determine the relative sizes of the particles or grains of which a given sample of stone or sand is composed, the different sizes are separated from each other by screening the material through successive sieves of increasing fineness. After sieving, the residue on each sieve is carefully weighed, and beginning with that which has passed the finest sieve, the weights are successively added, so that each sum will represent the total weight of the particles which have passed through a certain sieve. The sums thus obtained are expressed as percentages of the total weight of the sample and plotted upon a diagram with diameters of the particles as abscissæ and percentages as ordinates.

A convenient outfit for such a mechanical analysis as above described, consists of a set of sieves, an apparatus for shaking the sieves, and scales for weighing. A standard size of sieve is 8 inches in diameter and $2\frac{1}{4}$ inches high. Sieves with openings exceeding 0.10 inch are preferably made of spun hard brass with circular

* Taylor and Thompson " Concrete, Plain and Reinforced," p. 193.

openings drilled to the exact dimensions required. Sieves with openings of 0.10 inch and less are preferably of woven brass wire set into a hard brass frame. Woven brass sieves are made for many purposes, and are sold by numbers which are approximately the number of meshes to the linear inch. As the actual diameter of the hole varies with the gauge of wire used by different manufacturers, every set of sieves must be separately calibrated.

The number and sizes of sieves to be used depends upon the importance of the testing to be done. A convenient set of sieves for ordinary laboratory practice is given below in Table XL.

TABLE XL.—SIZES OF SAND AND STONE SIEVES

Stone Sieves, Diameter of Hole (Inches).	Sand Sieves.		
	Commercial No.	Diameter in Inches.	
		Hole.	Wire.
3.00	¼ in. round	.....	.....
2.50	No. 7	0.111	0.032
2.00	" 12	0.056	0.027
1.50	" 20	0.0335	0.0165
1.00	" 30	0.0198	0.0135
0.75	" 50	0.0120	0.0080
0.50	" 90	0.0059	0.0052
0.25	" 200	0.0029	0.0021

When many analyses are to be made, it is convenient to have a printed cross-section form, with appropriate spaces for filling in the number of the analysis, description of the material, location of the work, and other facts relating to the material.

For those who are unfamiliar with mechanical analysis, a detailed explanation of the method of locating the curve is here given. The method can best be understood by referring to the diagrams of typical materials which are also of practical interest as illustrating the curves which may be expected in special cases.

Fig. 139 represents a typical mechanical analysis of crusher-run micaceous quartz stone which has been run through a ¼-inch revolving screen so as to separate particles finer than ¼ inch, that is, the dust for use with sand.

For a sample of stone, which may be taken by the method of quartering * 1000 grams is a convenient quantity for 8-inch diameter

* The method of quartering consists in taking shovelfuls of the material from various parts of the pile, mixed together and spread in a circle. The circle is quartered, as one would quarter a pie; two of the opposite quarters are shoveled

sieves $2\frac{1}{4}$ inches in depth, and also permits of easy reduction from weights to percentages. To obtain the analysis shown in Fig. 139, the sample of stone is placed in the upper (coarsest) sieve of the nest of stone sieves given in Table XL, and after 1000 * shakes the nest is taken apart, and the quantity caught on each sieve is weighed, beginning with the finest and placing each successive residue on the scale pan with that already weighed. The results obtained in the particular case under consideration are illustrated in Table LXI, which shows the method of finding the percentages:

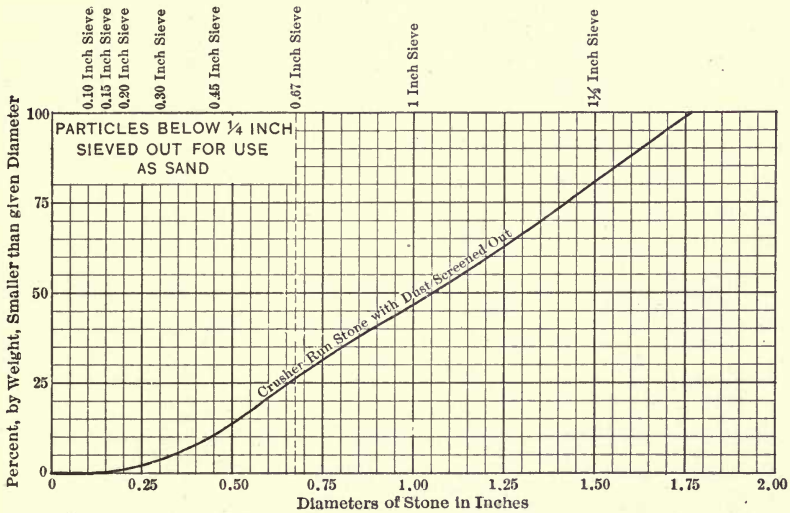


FIG. 139.—Typical Mechanical Analysis Curve of Crusher-run Micaceous Quartz Stone.

The various percentages are plotted on the diagram and the curve drawn through the points. The vertical distance from the bottom of the diagram to the curve, that is, the ordinate at any point, represents the percentage of the material which passed through a single sieve having holes of the diameter represented by this particular ordinate. Since the percentage of material passing any sieve is always the complement of the percentage of grains coarser than that sieve, the vertical distances from the top of the diagram down to the curve represents the percentages which would be retained

away from the rest, thoroughly mixed, spread, and quartered as before. The operation is repeated until the quantity is reduced to that required for the sample.

* In practice to-day the custom prevails of shaking the material until no more comes through as determined by successive weighings.

upon each sieve if employed alone. For example, taking 1.25, 62 per cent, the distance from the bottom of the diagram, represents the percentage of material finer than $1\frac{1}{4}$-inch diameter, and 38 per cent, the distance down from the top of diagram, represents the percentage coarser than $1\frac{1}{4}$ inch.

TABLE XLI.—RESULTS OF SCREENING SAMPLES OF STONE OF FIG. 140

Size Sieve.	Amount Finer than Each Sieve.	Percentage Finer than Each Sieve.
Inches	Grams	Per Cent
1.50	801	80
1.00	457	46
0.67	222	22
0.45	99	10
0.30	27	3
0.20	19	2
0.15	8	1
0.10	0	..

Typical curves of a fine, a medium well graded, and a coarse sand are shown in Fig. 140. For convenience in plotting, the horizontal

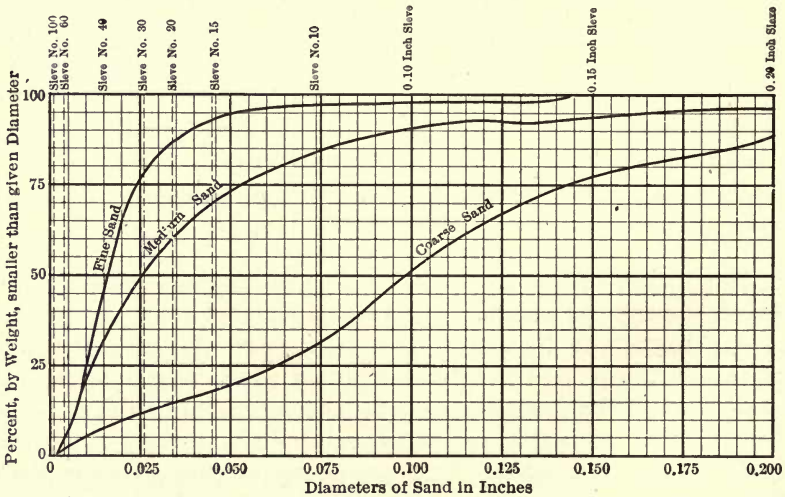


FIG. 140.—Typical Mechanical Analyses Curves of Fine, Medium, Well-graded, and Coarse Sands.

scale is ten times greater than that of Fig. 139, the diagram showing diameters ranging from 0 to 0.200 inch diameter.

The mechanical analysis of crusher dust is apt to vary between the curves of fine sand and medium sand which are shown in Fig. 140.

APPENDIX II

CONCRETE IN SEA WATER *

REGARDING the chemical action of sea water on concrete and its prevention, the following information and conclusions are presented here because of their bearing on and corroboration of the subject matter of Chapter I.†

Investigations concerning the effect of sea water on concrete immersed for periods up to fifty years or more; of the relative merits of standard Portland cement and Portland cement made with different proportions of its principal constituents, in resisting the disintegrating effect of sea water; of the effect of varying the proportions of cement in the mortar and concrete; of differently graded aggregates; of the addition of various finely ground materials to the cement after burning; of the relative durability of concrete cast in place as compared with concrete blocks allowed to harden before placing in the sea; and of the effect of various materials added to the concrete mixture to produce impermeability and consequent increased durability, have been made in European countries and in America.

Regarding the chemical action of sea water on cement, the following conclusions are presented:

Cement containing up to $2\frac{1}{2}$ per cent of sulphuric anhydride (SO_3) resists the action of sea water fully as well as cement with lower sulphuric anhydride content.

While all the hydraulic cements now in use are liable to decomposition in sea water, Portland cement is the one to be preferred in every respect.

High iron Portland cement and puzzolan cement have failed to show superiority over standard Portland cement in resisting the disintegrating effect of sea water.

* American Railway Engineering Association, Vol. 15, March, 1914, p. 564.

† For a presentation of practical results of marine construction and valuable conclusions drawn from observed effects of sea water on concrete all over the United States, see five articles by Rudolph J. Wig and Lewis R. Ferguson in Engineering News-Record, commencing Vol. 79, No. 12, 1917.

Regarding the effect of varying the proportions of cement in the mortar and concrete, in general, the richer mixtures have been found to offer better resistance to the attack of sea water. Proportions recommended for mortars are those with one part cement to one part of sand up to one part cement to two parts sand. The bad condition of mortars leaner than the above after exposure in sea water, stands out prominently.

In the use of reinforced concrete for maritime works, it is advisable to employ larger proportions of cement than are usual for similar works in fresh water.

Concerning the addition of finely ground material to the cement after burning, it has been found that the addition of ground puzzolan or furnace slag to Portland cement increases the resistance of the resulting mortar or concrete to the disintegrating effect of sea water.

Regarding the use of any material added to the concrete mixture in small quantities in order to reduce permeability, no results of practical working tests have demonstrated that the effect of any material in reducing permeability is other than mechanical, i.e., to supply a deficiency in fine material in a poorly graded concrete mixture.

Allowing the concrete to harden under favorable conditions before exposure to the action of sea water greatly increases its resistance to attack by the sea water and is recommended wherever possible.

When concrete is deposited under sea water, such precaution should be observed as will prevent the washing of the cement from the mixture.

Forms should be so tight as to prevent the entrance of sea water after depositing the concrete, in order that a smooth dense surface may be obtained.

The combined effect of freezing and of sea water is noted on marine structures in northern latitudes between high and low tide levels. Under these conditions the disintegrating effects are particularly severe.

Dense, properly hardened concrete is not affected by the action of sea water. Where the concrete is porous, however, it is likely to be damaged by frost action, especially between tides. There is no evidence, however, that porous concrete is damaged by sea water in latitudes where there is no frost.

The making of a dense, impermeable concrete by the use of a well-graded aggregate, rich mixture, proper consistency, and good workmanship, and allowing the concrete to harden under favorable conditions before being exposed to the action of sea water, is generally

conceded to be an efficient means of satisfactorily insuring the preservation of concrete in maritime works.

Concrete Subjected to the Action of Water Containing Alkalies. Investigations concerning the effect of ground waters which contain alkalies on concrete have disclosed several instances of apparent disintegration. The following points have been demonstrated in regard to the resistance of concrete to these agencies:

Concrete in which poor aggregates and lean mixtures have been used and in which the material has been carelessly placed, when coming in contact with alkali seepage may be affected thereby.

The aggregates should be composed of materials inert to alkalies present in the water. A chemical examination of the sand from country known to contain alkaline soils is recommended.

Water containing substances known to react with the elements of the cement should be kept from coming in contact with concrete until the latter has thoroughly hardened.

Care should be taken to provide a smooth surface and sufficient slope to the extrados of the arch of tunnel linings when the groundwater level lies below the tunnel grade to facilitate the flow of seepage water to the sides. The back filling over the arch should consist of porous material such as coarse, crushed stone, for the same reason. Side-drains should be used where necessary and connected with an underdrain, which should be provided in all cases.

The measures to be used in making concrete which is to be exposed to the action of these deteriorating agencies in order to prevent disintegration are the same as recommended for sea water construction. Impermeability is the prime requisite, and the results of experiments and practical tests indicate that concrete, carefully prepared, is just as resistant, if not more so, than if mixed with foreign materials or special preparations.

The following instructive conclusions on the effect of sea water on concrete are from a paper by Mr. W. Walters Pagon, read before the Engineers Club of Baltimore.* Though somewhat a repetition of the previous paper, its greater detail warrants its addition here.

In order to construct concrete that will have the greatest resistive power against the action of sea water (and also probably of alkali waters) it must possess the following characteristics:

The addition of puzzolan in some form is widely practiced in Europe and appears to be theoretically correct. It has not been tried in America, to the author's knowledge, but is worth an exhaus-

* "Concrete," Vol. 9, No. 4, October, 1916.

tive test. The amount should not be over one part nor less than one-half part for each part of cement.

Waterproofing with substances that combine chemically with the free lime ought to be successful and is worth testing.

Between extreme high and low tides the concrete surface should be faced continuously, without joints, with about 3 inches of 1 : 1½ or 1 : 2 mortar made with sand as specified below, well cured before coming in contact with the sea water. Facing must be placed simultaneously with the backing.

The cement should be low in lime and alumina and contain as little gypsum as possible.

Sand must be silicious, uniformly graded from fine to coarse, with not less than 50 per cent nor more than 70 per cent passing through a No. 20 sieve, and no more than 3 per cent passing a No. 100 sieve and must have no organic matter coating the grains. It must be free from roots and easily disintegrated grains, such as feldspar, shells, limestone, mica, etc. It should be washed free from clay, and should show a tensile strength for 1 : 3 specimens not less than the following percentages of the strength of standard Ottawa sand of the same consistency, using the brand of cement that is to be used on the work:

Age.	Percentage Strength.
1 day	85
7 days	95
28 days	100

Where concrete must be exposed to sea water without mortar facing, gravel should not be used. Broken stone should be hard, durable trap, granite or other dense, hard, insoluble stone. It should not exceed ¾ inch in size and should be free from crusher dust, sand, dirt, organic matter or other foreign substances. The mixture should be 1 : 1½ : 3 or 1 : 2 : 4 or should be proportioned for maximum density.

Pure fresh water should be used in sufficient quantity to permit the materials to be well puddled and spaded, so that no later surface treatment or patching will be required, but not sufficient to materially retard the setting of the cement. Care must be exercised, however, to prevent the formation of laitance or pockets of neat cement or very rich mortar.

Forms should be tight to prevent leakage of cement, or, where concrete must be submerged immediately, to prevent contact with the sea water.

Facing should be reinforced with steel well covered with mortar and securely anchored to the backing.

No surface treatment should be given.

The work should be allowed to harden for two weeks, if possible, before coming in contact with sea water. Two months is better.

Sea water work should never be done in cold weather, with temperature below 40 deg. Fahr. (4.4 deg. Cent.).

Where possible, pre-cast, mortar-faced blocks cured in damp sand for at least one month should be used. The mortar facing should not only be on the outside of the block, but should extend on the faces which form the bed joints and vertical joints. In this way the facing will be continuous, back to such a point, that no water can get into the rear of the block. The joints between the blocks should be pointed with 1 : 1 mortar of coarse sand to eliminate saturation.

The most durable surface will be obtained if granite or other dense stone be used as facing. This should not be less than 6 inches thick, anchored back with wrought-iron clamps and pointed with 1 : 1 mortar of coarse sand and cement as noted above.

On mortar or concrete surfaces the growth of barnacles, moss, etc., will frequently afford protection.

APPENDIX III

REPORT ON WATERPROOFING *

THE following report of Committee D–8 of the American Society for Testing Materials corroborates the author's information and experience in general waterproofing preceding and since its publication.

The committee reports that while it has not been able to arrive at sufficiently definite conclusions to enable it to formulate specifications for the making of concrete structures waterproof or for materials to be used in such work, it has reached certain general conclusions which may be of assistance to the constructor in securing the desired result of impermeable concrete.

Early in the investigation, the work was found to sub-divide naturally into three branches, and the conclusions reached will be grouped in order under these sub-divisions, which are:

1. The determination of causes of the permeability of concrete as usually made from mixtures of Portland cement, sand and stone, or other coarse aggregate, in proportions of from 1 cement, 2 sand and 4 stone, to 1 cement, 3 sand and 6 stone, and the best methods of avoiding these causes.

2. The rendering of concrete more waterproof by adding to ordinary mixtures of cement, sand and stone, other substances, which, either by their void-filling or repellent action, would tend to make the concrete less permeable.

3. The treatment of exposed surfaces after the concrete or mortar has been put in place and hardened more or less, either by penetrative, void-filling or repellent liquids, making the concrete itself less permeable or by extraneous protective coatings, preventing water having access to the concrete.

Considering these several sub-divisions separately and in the order named, the committee finds:

1. **Causes of Permeability of Concrete.** In the laboratory and under test conditions using properly graded and sized coarse and fine aggregates, in mixtures ranging from 1 cement, 2 sand and 4 stone, to 1 cement, 3 sand and 6 stone, impermeable concrete can invariably

* Proceedings, American Society for Testing Materials, Vol. 13, 1913, p. 459.

be produced. That even with sand of poor granulometric composition, with mixtures as rich as 1 cement, 2 sand and 4 stone, permeable concrete is seldom, if ever, found and is a rare occurrence with mixtures of 1 cement, 3 sand and 6 stone. But the fact remains, nevertheless, that the reverse obtains in actual construction, permeable concretes being encountered even with 1 cement, 2 sand and 4 stone mixtures and are of frequent occurrence where the quantity of the aggregate is increased. This we attribute to:

(*a*) Defective workmanship, resulting from improper proportioning, lack of thorough mixing, separation of the coarse aggregate from the fine aggregate and cement in transporting and placing the mixed concrete, lack of density through insufficient tamping or spading, and improper bonding of work joints, etc.

(*b*) The use of imperfectly sized and graded aggregates:

(*c*) The use of excessive water, causing shrinkage cracks and formation of laitance seams.

(*d*) The lack of proper provision to take care of expansion and contraction, causing subsequent cracking.

Theoretically, none of these conditions should prevail on properly designed and supervised work, and are avoided in the laboratory and in the field, under test conditions, where speed of construction and cost are negligible items, instead of being governing features as they must be in actual construction. Properly graded sands and coarse aggregares are rarely, if ever, found in nature in sufficient quantities to be available for large construction, and the effect of poorly graded aggregates in producing permeable concrete is aggrevated by poor and inefficient field work. Even if we could afford the added expense of screening and remixing the aggregates so as to secure proper granulometric composition to give the density required and to make untreated concretes impermeable, it is seemingly a commercial impossibility on large construction to obtain workmanship even approximating that found in laboratory work. It therefore seems that we can secure impermeable concrete most economically by adopting some special waterproofing treatment.

2. **Addition of Foreign Substances to Cement or During Mixture.** The committee finds that in consequence of the conditions outlined above, the use of substances calculated to make the concrete more impermeable, either incorporated in the cement or added to the concrete during mixing, has become general. This has resulted in the development and placing on the market of numerous patented or proprietary waterproofing compounds, the composition of which is more or less of a trade secret.

While it has been impossible for the committee to test all of the special waterproofing compounds being placed on the market, it has investigated a sufficient number of these, as well as the use of certain very finely divided, naturally occurring or readily obtainable commercial mineral products, such as finely ground sand, colloidal clays, hydrated lime, etc., to form a general idea of the value of the different types. The committee finds:

(*a*) That the majority of patented and proprietary integral compounds tested have little or no permanent effect on the permeability of concrete and that some of these even have an injurious effect on the strength of mortar and concrete in which they are incorporated;

(*b*) That the permanent effect of such integral waterproofing additions, if dependent on the action of organic compounds, is very doubtful;

(*c*) That in view of their possible effect, not only upon the early strength, but also upon the durability of concrete after considerable periods, no integral waterproofing material should be used unless it has been subjected to long-time practical tests under proper observation to demonstrate its value, and unless its ingredients and the proportion in which they are present are known;

(*d*) That in general, more desirable results are obtainable from inert compounds acting mechanically than from active chemical compounds whose efficiency depends on change of form through chemical action after addition to the concrete;

(*e*) That void-filling substances are more to be relied upon than those whose value depends on repellent action;

(*f*) That, assuming average quality in sizing of the aggregates and reasonably good workmanship in the mixing and placing of the concretes, the addition of from 10 to 20 per cent of very finely divided void-filling mineral substances may be expected to result in the production of concrete which under ordinary conditions of exposure will be found impermeable, provided the work joints are properly bonded, and cracks do not develop on drying or through change in volume due to atmospheric changes, or by settlement.

3. **External Treatments.** While external treatment of concrete would not be necessary if the concrete itself, either naturally or by the addition of waterproofing material, was impermeable to water, it has been found in practice that in large construction, no matter how carefully the concrete itself has been made, cracks are apt to develop, due to shrinkage in drying out, expansion and contraction under change of temperature, moisture content and through settlement.

It is, therefore, often advisable on important construction to anticipate and provide for the possible occurrence of such cracks by external treatment with protective coatings. Such coating must be sufficiently elastic and cohesive to prevent the cracks extending through the coating itself. The application of merely penetrative void-filling liquid washes will not prevent the passage of water due to cracking of the concrete. The committee has, therefore, divided surface treatments into two heads:

(*a*) Penetrative void-filling liquid washes.

(*b*) Protective coatings, including all surface applications intended to prevent water coming in contact with the concrete.

While many penetrative washes are efficient in rendering concrete waterproof for limited periods, their efficiency is apt to decrease with time and it may be necessary to repeat such treatment. Some of these washes may be objectionable, due to discoloring the surface to which they are applied. The committee, therefore, believes that the first effort should be made to secure a concrete that is impermeable in itself and that penetrative void-filling washes should only be resorted to as a corrective measure.

While protective extraneous bituminous or asphalt coatings are unnecessary, so far as the major portion of the concrete surface is concerned, provided the concrete—either in itself or through the addition of internal compounds—is made impermeable, they are valuable as a protection where cracks develop in a structure. It is therefore recommended that combination of the two methods—integral and extraneous waterproofing—be adopted in especially difficult or important work.

Considering the use of bituminous or asphaltic coatings, the committee finds:

(*a*) That such protective coatings are often subject to more or less deterioration with time, and may be attacked by injurious vapors or deleterious substances in solution in the water coming in contact with them.

(*b*) That the most effective method for applying such protection is either the setting of a course of impervious brick, dipped in bituminous material, into a solid bed of bituminous material, or the application of a sufficient number of layers of satisfactory membranous material cemented together with hot bitumen.

(*c*) That their durability and efficiency are very largely dependent on the care with which they are applied.

Such care refers particularly to proper cleaning and preparation of the concrete to insure as dry a surface as possible before applica-

tion of the protective covering, the lapping of all joints of the membranous layers, and their thorough coating with the protective material. The use of this method of protection is further desirable because proper bituminous coverings offer resistance to stray electrical currents.

So far, the committee has considered only concretes of the usual proportions, namely, those ranging from 1 cement, 2 sand and 4 stone, to 1 cement, 3 sand, and 6 stone. It has been suggested that impermeable concretes could be assured by using mixtures considerably richer in cement. While such practice would probably result in an immediate impermeable concrete, it is believed by many that the advantage is only temporary, as richer concretes are more subject to check cracking and are less constant in volume under changes of conditions of temperature, moisture, etc. Therefore, the use of more cement in mass concrete would cause increased cracking, unless some means of controlling the expansion and contraction be discovered. With reinforced concrete the objection is not so great, as the tendency to cracking is more or less counteracted by the reinforcement.

It has also been suggested that the presence in the cement of a larger percentage of very fine flour might result in the production of a denser and more impermeable concrete, through the formation of a larger amount of colloidal gels.

Neither of these suggestions have been especially investigated by the committee. Both appeal to the committee, however, for the reason that they substitute active cementitious substances for the largely inactive void-filling materials previously recommended, thus increasing the strength of the concrete.

In conclusion, the committee would point out that no addition of waterproofing compounds or substances can be relied upon to completely counteract the effect of bad workmanship, and that the production of impermeable concrete can only be hoped for where there is determined insistance on good workmanship.

APPENDIX IV

GLOSSARY OF TERMS USED IN THE WATERPROOFING INDUSTRY

Acid Sludge. A waste mixture of sulphonated hydrocarbons resulting from the treatment of bitumens with sulphuric acid.

Aggregate. The inert material, such as sand, gravel, shell, slag or broken stone, or combinations thereof, with which the cementing material is mixed to form a mortar or concrete.

Albertite. A soft jet black mineral (asphaltic hydrocarbon) derived from petroleum by natural oxidation, obtained in Canada.

Alum. A white crystalline substance consisting of a hydrated double sulphate of aluminum and potassium. See Chapter V.

Anthracene. A waxy crystalline hydrocarbon found principally in coal tars.

Artificial Bitumens. Hydrocarbon residues produced by the partial or fractional distillation of bitumen.

Artificial Gilsonite. A product obtained from the distillation of a mixture of fish remains and wood and redistillation of the resulting oil.

Asbestine. A trade name for a certain grade of powdered asbestos used in paints as a filler.

Asbestos. A mineral of fibrous crystalline structure composed, chemically, of silicates of lime and magnesia, and alumina. See Chapter V.

Asbestos Felt. Sheets made of asbestos shreds. See Chapter V.

Ash Water Glass. Same as water glass.

Asphalt. Solid or semi-solid native bitumens, solid or semi-solid bitumens obtained by refining petroleums, or solid or semi-solid bitumens which are combinations of the bitumens mentioned with petroleums or derivatives thereof, which melt on the application of heat, and which consist of a mixture of hydrocarbons and their derivatives of complex structure, largely cyclic and bridge compounds.

Asphalt Cement. A fluxed or unfluxed asphaltic material, especially prepared as to quality and consistency.

Asphalt Mastic. A term frequently applied to refined asphalt, particularly to that obtained from bituminous rocks. A mixture of fine mineral matter and asphalt.

Asphalt Pavement. A pavement composed of a mixture of asphalt and sand or powdered mineral dust or both.

Asphalt Putty. A mixture of a liquid and a solid asphalt (and fine mineral matter, usually) or asphalt and coal-tar pitch, having a particular consistency.

Asphaltenes.* The components of the bitumen in petroleum, petroleum products, malthas, asphalt cements, and solid native bitumens, which are soluble in carbon disulphide, but insoluble in paraffin naphthas.

Asphaltic. Similar to, or essentially composed of, asphalt.

* Adopted by the American Reporters on Communication No. 10 at the third International Road Congress.

Asphaltic Coal. Solid forms of asphalt (originally derived from petroleum) which, through loss of their oil content, by oxidation, resemble glance coal.

Asphaltic Concrete. Broken stone bound together with asphaltic cement.

Asphaltic Limestone. Limestone or limestone sands naturally impregnated with asphalt or maltha, and known as " asphalt " in Europe.

Asphaltic Oils. Asphaltic petroleums.

Asphaltic Petroleums. Petroleums containing an asphaltic base.

Asphaltic Sandstone. Sandstone naturally impregnated with asphalt or maltha and known as " asphalt " in Europe.

Asphaltite. Same as asphaltic coal.

Asphaltum. The Latin form of the English word asphalt.

Bakelite. A hard amber-like substance manufactured from the coal-tar derivatives phenol and formaldehyde. See Chapter V.

Bank-run Gravel. The normal product of a gravel bank.

Barret Specification Felt. Trade name for a proprietary tar-treated roofing felt.

Baumé Gravity. An arbitrary scale of specific gravity or density of liquids, usually expressed as deg. Baumé, or ° B. on a hydrometer. See Chapter XII.

Benzene. Benzol (C_6H_6). See Chapter V.

Benzine. A light and volatile fraction of petroleum. See Chapter V.

Benzol. A light, volatile, colorless coal-tar distillate of the formula C_6H_6. See Chapter V.

Bermudez Asphalt. A very pure semi-solid native asphalt from Bermudez.

Binder. The bituminous cementing material employed in the membrane system of waterproofing.

Bitumen. A natural hydrocarbon mixture of mineral occurrence, widely diffused in various forms which grade by imperceptible degrees from a light gas to a solid; commercially the term includes only the heavy liquid and solid asphalts. Frequently coal-tar pitch is so referred to.

Bituminous. A term applied to materials containing bitumen.

Bituminous Cement. A bituminous material suitable for use as a binder having cementing qualities which are dependent mainly on its bituminous character.

Bituminous Emulsion. A mixture of a bituminous oil and water made miscible through the action of a saponifying agent or alkaline soap.

Bituminous Paints. Mixtures of liquid paraffin and asphalt or coal-tar; mixtures of bitumen with some drying oil. See Chapter V.

Bituminous Putty. A mixture of bituminous materials and whiting or other mineral, of a putty-like consistency.

Bituminous Rock. Same as rock asphalt.

Blown Asphalt. Asphalt through which air has been blown during the process of refining.

Blown Oils. Blown petroleum.

Blown Petroleum.* Semi-solid or solid products produced primarily by the action of air upon originally fluid native bitumens which are heated during the blowing process.

Building Paper. A paper, usually a heavy grade and strong, sized with rosin to make it water resisting and used to sheath buildings to exclude drafts.

*Adopted by the American Reporters on Communication No. 10 at the third International Road Congress.

Built-up Roofs. Roofing consisting of several plies of treated felt cemented with asphalt or coal-tar pitch. See Chapter III.

Burlap. A woven fabric made of jute. See Chapter V.

Byerlite. Common and trade-name of a blown asphaltic petroleum distinguished from ordinary blown petroleums principally by the use of oxygen instead of air in the blowing process.

Caffall Process. A proprietary process for applying paraffin to exterior masonry surfaces.

Calcium Compounds. Salts of metal calcium or lime. See Chapter V.

Caoutchouc. A hydrocarbon with the approximate formula of $C_{10}H_{16}$ and possessing properties similar to India rubber.

Carbenes.* The components of the bitumen in petroleums, petroleum products, malthas, asphalt cements, and solid native bitumens, which are soluble in carbon disulphide, but insoluble in carbon tetrachloride.

Carbon Bisulphide. The volatile and extremely inflammable compound of carbon and sulphur (CS_2).

Carbon Disulphide. Same as carbon bisulphide.

Carbon Tetrachloride. A volatile noninflammable compound of carbon and chlorine ($C Cl_4$).

Carborundum. An artificial abrasive material resulting from the burning, in an electric furnace, of a mixture of sand, coke, sawdust and salt.

Casein. An albumin found in milk. See Chapter V.

Cement. An adhesive substance used for uniting particles of materials to each other. Ordinarily applied, only to calcined "cement rock," or to artificially prepared, calcined, and ground mixtures of limestone and silicious materials. Sometimes used to designate bituminous binder used in waterproofing.

Cement Floor. A name commonly applied to concrete floors with or without a mortar top.

Cerasin. Ozocerite.

Cerite. Ozocerite.

China Clay. Kaolin.

Chinawood Oil. Oil pressed from the seeds of the wood-oil tree of China and Japan. See Chapter V.

Choctaw. Name of mining locality (in Oklahoma) of grahamite; sometimes, but incorrectly used for grahamite.

Clay. Finely divided earth, generally silicious and aluminous, which will pass a 200-mesh sieve.

Coal Tar. The mixture of hydrocarbon distillates, mostly unsaturated ring compounds, produced in the destructive distillation of coal. See Chapter V.

Coal-tar Pitch. The residue (of a viscous consistency) resulting from the distillation of coal-tar. See Chapter V.

Coat. (1) The total result of one or more surface applications. (2) To apply a coat.

Coke-oven Tar. Coal tar produced in by-product coke ovens in the manufacture of coke from bituminous coal. See Chapter V.

Colloidal Material. A gelatinous substance, resembling glue or jelly, and consisting of microscopically fine particles of matter.

Colophony. Rosin.

* Adopted by the American Reporters on Communication No. 10 at the third International Road Congress.

Compressed Asphalt. A European (particularly French) term for rock asphalt pavement.

Concrete Floor Hardener. A powdered metal or mineral usually troweled on, or a liquid chemical reagent usually brushed on, the surface of a concrete floor to harden same.

Concrete Primer. A thin liquid compound applied as a first coat to a concrete surface preparatory to being coated with a more viscous compound.

Consistency.* The degree of solidity or fluidity of bituminous materials.

Corundum. A crystalline mineral abrasive mined in the United States and ground for use.

Cotton Drill. A woven cotton fabric. See Chapter V.

Cracked Oil. Petroleum residuum which have been overheated in the process of manufacture.

Cracking. The process of breaking down hydrocarbon molecules by the application of heat.

Crude Asphalt. Unrefined asphalt.

Crude Oil. Unrefined oil.

Crude Tar. Unrefined coal tar.

Cut-back Products. Petroleum, or tar-residuums, which have been fluxed each with its own or similar distillate, to a desired consistency.

Dampproofing. The process of treating masonry internally or externally, to prevent dampness or moisture from penetrating the masonry.

Dead Oils. Heavy oils with a density greater than water distilled from tars.

Dehydrated Tars. Crude tar from which all water has been removed.

Destructive Distillation. The distillation of organic compounds at sufficiently high temperatures so that their identity is destroyed.

Dipping Compound. Bituminous compound used for coating pipes and iron tunnel segments to preserve them against rust.

Drainage. Provision for the disposition of water in or about a structure.

Dust. Earth or other matter in fine, dry particles, so attenuated that they can be raised and carried by air currents. The product of the crusher passing through a fine sieve.

Eastern Petroleum. Petroleum found in the eastern part of the United States, principally Pennsylvania.

Elaterite. A soft elastic variety of asphalt, resembling rubber, Also an appropriated name of a proprietary waterproofing compound. See Chapter V.

Emulsion. A combination of water and oily material made miscible through the action of a saponying agent.

Expansion Joint. A separation of the mass of a structure, usually in the form of a joint filled with elastic material, which provides the means for slight movement in the structure.

Fabric. A cotton cloth or burlap treated with asphalt or coal-tar pitch.

Felt. A soft form of paper sheet composed chiefly of pulp and rags and saturated with coal-tar pitch or asphalt. See Chapter V.

Filler. (1) Relatively fine material used to fill the voids in concrete aggregate. (2) Material used to fill the voids in expansion joints.

Fixed Carbon.* The organic matter of the residual coke obtained upon burning hydrocarbon products in a covered vessel in the absence of free oxygen.

Flashing. A piece of metal or other waterproof material used to keep water

* Adopted by the Am, Soc. for Testing Materials.

from penetrating the joints between a wall or projection, and the roof or other flat part of the structure. See Chapter III.

Floating. Smoothing, with a trowel, the surface of mortar or concrete.

Flux.* Bitumens, generally liquid, used in combination with harder bitumens for the purpose of softening the latter.

Free Carbon. In tars, organic matter which is insoluble in carbon bisulphide. See Chapter VII.

Fuller's Earth. A fine-grained earthy material of cretaceous formation and resembling clay in appearance.

Furring Compound. A compound used to bond plaster to masonry.

Gaging Water. Water (in measured quantities) used in mixing mortar or concrete to a required consistency.

Gas Black. Soot from natural gas.

Gas-drip. A condensate from illuminating gas, present to a greater or less degree in all gas mains and tanks and an effective solvent of most bituminous materials.

Gas-house Coal Tar. Coal-tar produced in gas-house retorts in the manufacture of illuminating gas from bituminous coal.

Gasoline. A very volatile distillate of petroleum. See Chapter V.

German Wax. A manufactured wax or blend of beeswax and other waxes.

Gilsonite. Glance pitch; a pure hard lustrous asphalt found principally in Utah, U. S. A. See Chapter V.

Glance Pitch. A very pure solid asphalt or gum asphalt.

Grahamite. A pure, solid lusterless asphalt. See Chapter V.

Graphite. A soft dark-colored form of carbon with considerable luster. See Chapter V.

Gravel. Small stones or pebbles, usually found in natural deposits more or less intermixed with sand, clay, etc., but in which mixture the particles which will not pass a 10-mesh sieve predominate.

Grit. Stone chips, slag chips, small pebbles or rounded rock particles graded or ranging in size between $\frac{1}{8}$ and $\frac{3}{8}$ inch.

Ground Water. That part of rain, hail, or snow, that has percolated through and accumulated in the ground as water chiefly in consequence of an underlying impervious strata.

Ground-water Level. The upper surface of ground water. See Chapter I.

Grout. A mixture of cement and water or cement sand and water of thinner consistency than mortar. See Chapter V.

Grouting. The process of injecting grout or mortar to fill small holes and seams in and around subsurface structures. See Chapter II.

Gum. Varnish gum; loosely applied to asphalt.

Gum Resins. Resins exuding from cuts in pines.

Gumlac. Shellac.

Gunite. Trade name for the mortar made and "shot" from the cement gun. See Chapter II.

Gutta-percha. A substance consisting of a dried milky juice in many respects similar to caoutchouc, but not elastic; extracted from certain trees in the tropics.

Gypsum. Erroneously referred to as plaster of Paris but actually a hydrated calcium sulphate ($CaSO_4$, $2H_2O$).

* Adopted by the American Reporters on Communication No. 10 at the third International Road Congress.

High Carbon Tars. Tars containing a high percentage of free carbon (between 15 and 25 per cent).

Hot Stuff. Washing soda (carbonate of lime) when used to quicken the setting time of mortar. Colloquially, also hot molten asphalt, or coal-tar pitch, or mastic made from these.

Hydrated Lime. A finely divided white powder, made of ordinary lime to which has been added just sufficient water to insure complete slaking, and leaving the product dry. See Chapter V.

Hydrocarbons. Chemical compounds composed of the elements hydrogen and carbon.

Hydrolithic. Proprietary trade name applied to the integral system of waterproofing.

Hydrolytic. Name commonly applied to materials used in integral waterproofing which tend to prevent the percolation of water through the treated masonry.

Hydrex Compound. Trade name for a proprietary asphalt.

Imitatite. A black, hard variety of bitumen.

Impsomite. A solid bitumen resembling gilsonite, found in Oklahoma, U. S. A.

Integral Compound. A material incorporated in mortar or concrete, previous to or during mixing, to waterproof same. See Chapter II.

Integral System. The process of incorporating waterproofing materials in mass mortar or concrete. See Chapter II.

Iron (Powdered). Cast iron or pig iron in powder form.

Isinglass. The dried swimming bladders of several varieties of fish from which gelatine is extracted.

Joint Filler. Any compound used for filling joints between moving parts of steel or masonry (structures) subject to expansion, contraction and vibration. See Chapter IV.

Kaolin. A fine clay the purity of which gives it a white color.

Lake Pitch. A plastic porous, and about 50 per cent impure asphalt from the asphalt "lake" in the island of Trinidad.

Land Pitch. A surface deposit of solid Trinidad Lake asphalt which is tougher and more tenacious than the "lake" asphalt.

Land Plaster. Powdered gypsum; also, but incorrectly, used to designate plaster of Paris.

Lap Cement. A liquid bituminous compound used for cementing the laps of ready roofing.

Larutan Compound. Trade name of a proprietary asphalt.

Larutan System. Application of a waterproofing membrane in the form of small squares of asphalt-treated cotton fabric. See Chapter II.

Layer. A course or coat made in one application.

Lime. A white substance resulting from the burning of limestone. See Chapter V.

Linseed Oil. Oil obtained from the seed of flax by pressing. See Chapter V.

Lithocarbon. A commercial name for an asphaltic limestone found in Uvalde, Texas, U. S. A.

Low Carbon Tars. Tars containing a low percentage of free carbon (between 5 and 15 per cent).

Maltha. A natural or artificial asphalt containing sufficient lighter compounds to be liquid.

Malthene. Those portions of asphalt and similar materials soluble in both carbon bisulphide and petrolic ether and not readily volatile at a temperature of 163 deg. Cent.

Manjak. A pure, black, lustrous bitumen from Barbadoes, probably related to grahamite.

Mastic. A mixture of fine mineral matter and asphalt or coal-tar pitch, applicable in a heated condition. See Chapter V.

Mastic Rock. Rock asphalt.

Membrane. In waterproofing, a thin layer or layers of bituminous material with or without fabric reinforcement, placed on or about a structure.

Membrane System. The system of applying an elastic, membranous waterproofing material. See Chapter II.

Metal Primer. A first coat of paint or preserving compound applied to iron or steel.

Mineral Naphtha. A volatile petroleum distillate heavier than gasoline.

Mineral Oil. Petroleum.

Mineral Pitch. A popular name for asphalt.

Mineral Rubber. A bitumen of rubbery consistency.

Mineral Tar. A liquid bitumen, of a viscid, tarry nature.

Mineral Wax. A common term for ozocerite.

Minwax. A proprietary asphalt.

Mortar. A mixture of sand, cement, or lime (or both) and water mixed to a paste consistency.

Naphtha. A volatile petroleum hydrocarbon distillate heavier than gasoline.

Naphthalene. A white solid crystalline hydrocarbon, occurring principally in coal tar, of the chemical formula $C_{10}H_8$.

Native Bitumens. Bitumens occurring in nature, and for waterproofing purposes, generally as liquids, viscous liquids or solids.

Native Paraffin. Ozocerite.

Natural Cement. A fine cementing powder made by burning and grinding a cement rock at a somewhat lower heat than Portland cement. See Chapter V.

Neponsit Felt. Trade name for a proprietary roofing felt.

Neutral Oil. Neutral mineral oil.

Oil Asphalts. Artificial oil pitches or asphaltic cements produced as a residuum from asphaltic petroleum.

Oil Pitches. More or less hard oil asphalts.

Oil-gas Tars. Complex hydrocarbon liquids produced by cracking oil vapors at high temperatures in the manufacture of oil gas or carburetted water gas.

Oil-tar Pitch. A viscous residuum of any desired consistency from the distillation of oil tars. See Chapter V.

Ozocerite. A yellow or brown hydrocarbon, greasy, waxlike substance, occurring in the form of small veins in tertiary rock in Galacia, Austria and Utah, U. S. A.

Ozokerite. Same as Ozocerite.

Paraffin. Commonly, the same as paraffine; a hard, white, wax-like substance, chemically of the higher hydrocarbons. See Chapter V.

Paraffine. A term covering a number of greasy crystalline hydrocarbons of the paraffin series.

Paraffin Naphtha. Naphtha from paraffin petroleum.

Paraffin Oil. A heavy liquid fraction of the manufacture of paraffin from petroleum. See Chapter V.

Paraffin Petroleum. Petroleum, the base of which is principally of the paraffin series of hydrocarbons.

Paraffin Scale. Solid paraffins in asphalt. See Chapter V.

Petrolene. Those portions of asphalt and similar materials which are soluble both in carbon bisulphide and petrolic ether, and which are volatile at 163 deg. Cent. and below.

Petroleums. Native mineral oils or fluid native bitumens of variable composition.

Petrolic Ether. A volatile naphtha lighter than gasoline, obtained from petroleum.

Pine Oil. A heavy distillate of rosin.

Pine Tar. Gum of the pine tree from an incision or by distillation of the wood; common rosin.

Pipe Coating. A bituminous compound applied hot or cold to iron or steel pipes for preservation purposes.

Pitch. A sticky resin from pine tar. Semi-solid or solid residues from the distillation of bitumen; usually applied to residue obtained from tar. Short, for coal-tar pitch.

Pitch (Hard). Pitch showing a penetration of not more than ten.

Pitch (Soft). Pitch showing a penetration of more than ten.

Pitch (Straight-run).* A pitch run in the initial process of distillation, to the consistency desired without subsequent fluxing.

Plaster Bond. Name of various bituminous compounds used for bonding plaster to masonry walls, and which also serve as dampproofing mediums.

Plaster of Paris. A hydraulic cement; a chalky powder resulting from the calcination of pure gypsum (a hydrated calcium sulphate) at a temperature between 250 and 400 deg. Fahr. losing thereby three-quarters of its water of combination.

Plastic Roofing. A plastic (when warm) roofing compound applied with a trowel, composed of some fine or fibrous inert substance mixed with tar or other bitumen.

Plastic Slate. A mixture of coal tar and powdered slate.

Portland Cement. A fine cementing powder made by carefully burning and grinding a cement rock or an artificial mixture of limestone and clay. See Chapter V.

Primer. A first coat applied to masonry preparatory to receiving the successive coats of material for waterproofing or dampproofing purposes.

Puzzolan Cement. A very fine cementing powder made by mechanically mixing and powdering slaked lime and volcanic ash or slag.

Pyrobitumens. Mineral organic substances forming bitumens upon being subjected to destructive distillation.

Pyrogenetic. That which originates from the action of heat.

Quasi-colloidal Bodies. Like, or nearly colloidal, particles.

Quasi-soap. Like, or as if it were, soap.

Red Rope Paper. A red variety of building paper partly composed of rope waste.

Reduced Oils. Reduced petroleums.

* Proposed by the Committee on Standard Tests for Road Materials (Committee D–4) of the American Society for Testing Materials.

Reduced Petroleums. Residual oils from crude petroleum after removal of water and some volatile oils, but with the base chemically unaltered.

Refined Asphalt. Bitumen after it has been freed wholly or in part from its impurities.

Refined Tar. A tar freed from water by evaporation or distillation which is continued until the residue is of desired consistency or a product produced by fluxing tar residium with tar distillate.

Residual Oils. Residual petroleums.

Residual Petroleum. Viscous residue from the distillation of crude petroleum with all the burning oils removed.

Residual Tars. Tar pitch or viscous residue from the distillation of crude tar with all the light oils removed.

Resin. A dried and hardened pitch from pine and similar trees. See Chapter V.

Rock Asphalt. A solid asphalt obtained from a naturally impregnated limestone or sandstone, also the naturally impregnated stone.

Roofing Cement. A plastic mixture of paint skins, coal tar, pine tar and soya oil commonly used to seal flashing joints.

Roofing Gravel. Approximately $\frac{5}{8}$-inch gravel.

Roofing Slag. Slag crushed to the size ranging between $\frac{1}{4}$ and $\frac{1}{2}$-inch.

Rosin. Pine pitch with the chemical formula $C_{44}H_{62}O_4$. See Chapter V.

Salammoniac. Ammonium chloride; a white crystalline soluble substance (NH_4Cl). See Chapter V.

Sand. Finely divided rock detritus the particles of which will pass a 10-mesh and be retained on a 200-mesh screen.

Sand Cement. A very fine cementing powder made by grinding together a mechanical mixture of Portland cement and pure, clean sand.

Semi-asphaltic Oils. Semi-asphaltic petroleum.

Semi-asphaltic Petroleum. Petroleum of a semi-asphaltic base.

Sheet Mastic. Bituminous mastic in the form of a sheet used for paving and waterproofing purposes. See Chapter II.

"Short." A term applied to materials possessing little ductility.

Soap. A metallic salt of fatty acid. See Chapter V.

Soda Ash. Washing soda (carbonate of lime) of the chemical formula (Na_2CO_3, $10H_2O$).

Soluble Glass. Water glass.

Stearate. A salt of stearic acid. See Chapter V.

Stearic Acid. A derivative product of the more solid fats of the animal kingdom. ($CH_3(CH_2)_{16}COOH$). See Chapter V.

Stearin. The chief ingredient of suet and tallow. See Chapter V.

Stearin Pitch. A black, elastic, non-brittle, animal by-product obtained from stearic acid in the manufacture of candles. See Chapter V.

Subway Asphalt. Common name for a particular quality of asphalt used in waterproofing the New York Subways. See Chapter VIII.

Subway Pitch. Common name for a straight-run coal-tar pitch used in waterproofing subways in New York City. See Chapter VIII .

Suet. The hard and semi-fusible fat about the kidneys and loins of animals. See Chapter V.

Surface Coating. Any compound applied to a masonry surface for dampproofing or waterproofing purposes.

Sylvester Process. The process of applying alternate coats of soap and alum solutions for waterproofing and dampproofing purposes. See Chapter II.

Tar Pitches. Semi-solid or solid residual tars.

Tar. Bitumen which yields pitch upon fractional distillation and which is produced as a distillate by the destructive distillation of bitumens, pyrobitumens, or organic material. See Chapter V.

Texene. A trade name for a turpentine substitute.

Torpedo Gravel. A coarse hard grit.

Trinidad Asphalt. A solid or semi-solid asphalt, brown to black in color, porous and about 50 per cent impure, obtained from the island of Trinidad.

Turrellite. A black, hard variety of bitumen.

Vintaite. Gilsonite.

Varnish Gum. Any resinous substance excluding rosin. A term used to designate, but incorrectly so, asphalt and coal tar when used in proprietary waterproofing compounds.

Viscosity. The measure of the resistance to flow of a bituminous material, usually stated as the time of flow of a given quantity of the material through a given orifice.

Volatile. Applied to those fractions of bituminous materials which will evaporate at climatic temperatures.

Water Absorbent. A property of a floor-hardening or waterproofing material which makes it readily miscible with water.

Water Glass. Sodium silicate ($Na_2Si_4O_9$) or alkaline silicates soluble in water.

Water Repellent. A property of a waterproofing material which hinders or prevents its miscibility with water.

Water Table. Loosely applied to ground-water level.

Waterproofing. The process of treating masonry to exclude or prevent the percolation of moisture or water through it.

Water-gas Tar. A liquid hydrocarbon produced by cracking oil vapors in the manufacture of carburetted water-gas. See Chapter V.

Wurtzelite. A black, hard variety of bitumen.

APPENDIX V

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